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THE PROBLEM OF THE METALLIFEROUS VEINS.[1]

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The rush of the gold-seekers to California in 1849, and the quickly following one to Australia in 1851 were notable migrations in search of the yellow metal, but they were not the first in the history of our race. There is, indeed, no reason to suppose that, in the past, mining excitements were limited even to the historical period; on the contrary the legends of the golden fleece, and of the golden apples of the Hesperides probably describe in poetic garb two of the early expeditions, and long before either we can well imagine primitive man hurrying to new diggings in order to enlarge his scanty stock of metals. Among the influences which have led to the exploration and settlement of new lands, the desire to find and acquire gold and silver has been one of the most important, and as a means of introducing thousands of vigorous settlers, of their own volition, into uninhabited or uncivilized regions there is no agent which compares with it. In this connection it may be also remarked that there is no more interesting chapter in the history of civilization, than that which concerns itself with the use of the metals and with the development of methods for their extraction from their ores. Primitive man was naturally limited to those which he found in the native state. They are but few, viz., gold in wide but sparse distribution in gravels; copper in occasional masses along the outcrops

[1] Presidential address to the New York Academy of Sciences, read at the annual meeting in New York, December 18, 1905.

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of veins, in which far the greater part of the metal is combined with oxygen or sulphur; copper again, in porous rocks, as in the altogether exceptional case of the Lake Superior mines; iron in an occasional meteorite, which, if its fall had been observed, was considered to be the image of a god, descended from the skies;[1] silver in occasional nuggets with the more common ones of gold; and possibly a rare bit of platinum. Besides these no other metal can have been known, because all the rest and all of those mentioned, when locked up in their ores, give in the physical properties of the latter, but the slightest suggestion of their presence. Chance discoveries must have first revealed the possibilities of producing iron from its ore—really a very simple process when small quantities are involved—; of making bronze from the ores of copper and tin; of making brass with the ores of copper and zinc; of reducing copper and lead from their natural compounds; and of freeing silver from its chief associate, lead. All of these processes were extensively practised under the Chinese, Phenicians, Greeks, Romans and other ancient peoples.

As the need of weapons in war, the advantages of metallic currency and the want of household utensils became felt, and as the minerals which yield the metals became recognized as such, the art of mining grew to be something more than the digging and washing of gravels; and in the long course of time developed into its present stage as one of the most difficult branches of engineering. Chemistry raised metallurgical processes from the art of obtaining *some of a metal* from its ore, to the art of obtaining *almost all* of it and of accounting for what escaped. It is, in fact, in this scientific accounting for everything, that modern processes chiefly differ from those of the ancients.

Of all the metals the most important which minister to the needs of daily life are the following, ranged as nearly as possible in the order of their usefulness. Iron, copper, lead, zinc, silver, gold, tin, aluminum, nickel, platinum, manganese, chromium, quicksilver, antimony, arsenic and cobalt. The others are of

[1] As in the case of Diana of the Ephesians and the deity of the Carthaginians.

very minor importance, although often indispensable for certain restricted uses.

The manner of occurrence of these metals in the earth, and their amounts in ores which admit of practicable working are fundamental facts in all our industrial development, and some accurate knowledge of them ought to be a part of the intellectual equipment of every well-educated man. The matter may well appeal to Americans, since the United States have developed within a few years into the foremost producer of iron, copper, lead, coal, and until recent years in gold and silver; but with regard to gold, they have of late alternated in the leadership with the Transvaal and Australia, and in silver are now second to Mexico.

Despite the enormous product of food-stuffs, American mining developments are of the same order of magnitude; and the mineral resources of the country have proved to be one of the richest possessions of its people.

We may best gain a proper conception of the problem of the metalliferous veins, if we state at the outset the gross composition of the outer portion of the globe, so far as geologists have been able to express it by grouping analyses of rocks. We may then note among the elements mentioned, such of the metals as have just been cited and may remark the rarity of the others; we may next set forth the necessary percentages of each metal which make a deposit an ore, that is, make it rich enough for profitable working. By comparison we can grasp in a general way the amount of concentration which must be accomplished by the geological agents in order to collect from a naturally lean distribution in rocks enough of a given metal to produce a deposit of ore; and can then naturally pass to a brief discussion and description of those agents and their operations.

If the general composition of the crust of the earth is calculated as closely as possible on the basis of known chemical analyses, the following table results, which has been compiled by Dr. F. W. Clarke, of Washington, chief chemist of the U. S. Geological Survey.[1]

[1] Bulletin 148, p. 13

Oxygen	47.13
Silicon	27.89
Aluminum	8.13
Iron	4.71
Calcium	3.53
Magnesium	2.64
Potassium	2.35
Sodium	2.68
Titanium	.32
Hydrogen	.17
Carbon	.13
Phosphorus	.09
Manganese	.07
Sulphur	.06
Barium	.04
Chromium	.01
Nickel	.01
Strontium	.01
Lithium	.01
Chlorine	.01
Fluorine	.01
Total	100.00

Elements less than .01 per cent. are not considered abundant enough to affect the total, and equally exact data regarding them are not accessible. Among those given only the following appear which are metals of importance as such in every day life; aluminum 8.13, iron 4.71, manganese .07, chromium .01 and nickel .01. They rank respectively in the table, third, fourth, thirteenth, sixteenth and seventeenth. Of the five, iron is the only one of marked prominence. No one of the remaining four is comparable in usefulness with at least five other metals which are not mentioned, viz., copper, lead, zinc, silver and gold.

An endeavor has been made by at least one investigator, Professor J. H. L. Vogt, of Christiania, to establish some quantitative expression for these other metals. His estimates are as follows:[1]

Copper percentage beyond the fourth or fifth place of decimals, that is in the hundred thousandths or millionths of a per cent.

Lead and zinc, percentages in the fifth place of decimals or in the hundred thousandths of a per cent.

[1] *Zeitschrift für prak. Geologie*, 1898, 324.

Silver, percentage, two decimal places beyond copper—or in the ten millionths to the hundred millionths of a per cent., or the ten thousandth to the hundred thousandth of an ounce to the ton.

Gold, percentage, one tenth as much as silver.

Tin, percentage in the fourth or fifth decimal place, that is, in the ten thousandths or hundred thousandths of a per cent.

These figures, inconceivably small as they are, convey some idea of the rarity of these metals as constituents on the average of the outer six or eight miles of the earth's crust. But they are locally more abundant in particular masses of eruptive rocks which are associated with ore deposits.

In the following tabulation I have endeavored to bring together a number of determinations which have been made in connection with investigations of American mining districts. In a general way they give a fair idea of the metallic contents of certain eruptive rocks from which were taken samples as little as possible open to the suspicion that they had been enriched by the same processes which had produced the neighboring ore-bodies.

	Per Cent. in Eruptive Rocks	From.
Copper,	.009	Missouri.[1]
Lead,	.0011	Colorado.[2]
Lead,	.008	Eureka, Nev.[3]
Lead,	.004	Missouri.[1]
Zinc,	.0048	Leadville, Colo.[4]
Zinc,	.009	Missouri.[1]
Silver,	.00007	Leadville, Colo.[5]
Silver,	.00016	Eureka, Nev.[5]
Silver,	.00016	Rosita, Colo.[6]
Gold,	.00002	Eureka, Nev.[5]
Gold,	.00004	Owyhee Co., Id.[7]

[1] Average of eight eruptives from Missouri, Anal. by J. D. Robertson. Report on Lead and Zinc, Mo. Geol. Surv., II., 479.

[2] Average of six different rocks, embracing eighteen assays; S. F. Emmons, Monograph XII., U. S. Geol. Surv., 591.

[3] One rock, a quartz porphyry, not certain the rock was not enriched. J. D. Curtis, U. S. Geol. Surv., Mono. VII., 136.

[4] Same reference as under 6. The zinc was determined in but two samples.

[5] Same reference as under 6, but p. 594.

[6] S. F. Emmons, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p. 471.

[7] A. Simundi in Tenth Census, XIII., 54.

In order to come within the possible limits of profitable and successful treatment the ores of the more important metals should have at least the following percentages, but that we may grasp the relations correctly, it must be appreciated that local conditions affect the limits. Thus in a remote situation and with high charges for transportation an ore may be outside profitable treatment although it may contain several times the percentages of those more favorably situated. Iron ores in particular which are distant from centers of population, are valueless unless cheap transportation on a very large scale can be developed, while gold in an almost inaccessible region, like the Klondike, may yield a rich reward, even when in quantities which, if expressed in percentages, are almost inappreciable.

The nature of the ore is also a factor of prime importance. Some compounds yield the metals readily and cheaply, while, others, which in the case of the precious metals are often called base ores, require complicated and it may be expensive metallurgical treatment. The association of metals is likewise of the highest importance. Copper or lead, for example, greatly facilitates the extraction of gold and silver, whereas zinc in large quantities is a hindrance. Conditions also change. An ore which may have been valueless in early days may prove a rich source of profit in later years and under improved conditions. For instance, from 1870 for over twenty-five years Bingham Canyon in Utah yielded lead-silver ores and minor deposits of gold. It was known that in some mines low-grade and base ores of copper and gold existed but the fact was carefully concealed and in at least one instance the shaft into them was filled up, lest a general knowledge of the fact should unfavorably affect the value of the property. To-day, however, these ores are eagerly sought and their extraction and treatment in thousands of tons daily are paying good returns on very large capitalization. Another factor is the expense of extraction. If simple and inexpensive methods are possible, the area of profitable treatment is greatly widened. Thus gold may need little else than a stream of water or even a blast of air, whereas iron and copper require huge furnaces and vast supplies of coke and fluxes.

Iron ores are of little value in any part of the world unless they contain a minimum of 35 per cent. iron, when they enter the furnace, but if they are distributed in amounts of 10–20 per cent., in extensive masses of loose or easily crushed rock in such condition that they can be cheaply concentrated up to rich percentages, they may be profitably treated and a product with 50 per cent. iron or higher be sent to the furnaces. Nevertheless, speaking for the civilized world at large it holds true that as an iron ore enters the furnace, it can not have less than 35 per cent., and in America with our rich and pure deposits on Lake Superior two thirds of our supply ranges from 60–65 per cent.

As regards copper a minimum working percentage, amid favorable conditions and with enormous quantities is usually about 3 per cent., but in the altogether exceptional deposits of the native metal in the Lake Superior region, copper-rock as low as three fourths of one per cent. has been profitably treated. This or any similar result could only be accomplished with exceptionally efficient management and with a copper rock such as is practically only known on Lake Superior. With the usual type of ore, not enriched by gold or silver, two per cent. is the extreme and in remote localities five to ten may sometimes be too poor.

In southeast Missouri, lead ores are profitably mined which have 5–10 per cent. lead, but they are concentrated to 65–70 per cent. before going to the furnace.

Zinc ores at the furnace ought not to yield less than 25–30 per cent., and when concentrated or selected they range up to 60 per cent.

The precious metals are expressed in troy ounces to the ton avoirdupois. A troy ounce in a ton is one three-hundredth of one per cent., and the amount is, therefore, very small when stated in percentages. If it be appreciated that in round numbers silver is now worth fifty to sixty cents an ounce and gold twenty dollars, some grasp may be had of values. Silver rarely occurs by itself. On the contrary it is obtained in association with lead and copper and the ores are, as a rule, treated primarily for these base metals and then from the latter the precious metals are later separated. In the base ores there ought to be enough silver to

yield a minimum of five dollars or ten ounces in the resulting ton of copper in order to afford enough to pay for separation. Now in a five per cent. ore of copper we have a concentration of twenty tons of ore to yield one ton of pig, or more correctly stated, so as to allow for losses, twenty-one tons to one. We must, therefore, have at least ten ounces of silver in the twenty-one tons, which implies a minimum of about one half ounce per ton. Smelters will only pay a miner for the silver if he has over one half ounce per ton in a copper ore. In a pig of lead, usually called base bullion, it is necessary for profitable extraction to have fifteen ounces of silver. For smelting a lead ore we must possess at least ten per cent. lead and may have seventy. It is, therefore, obvious that from two to twenty ounces silver must be present in the ton of lead ore. The common ranges are ten to fifty ounces or one thirtieth to one sixth of one per cent.

Gold is so cheaply extracted that it may be profitably obtained under favorable circumstances down to one tenth of an ounce in the ton, but the run of ores is from one fourth ounce or five dollars to one ounce or twenty dollars. Ores of course sometimes reach a number of ounces. In copper or lead ores even a twentieth of an ounce may be an object and in favorably situated gravels, to which the hydraulic method may be applied, even as little as seven to ten cents in the cubic yard may be recovered, or some such value as one two-hundredth to one three-hundredth of an ounce per ton.

The tin ores as smelted contain about 70 per cent. but they are all concentrated either by washing gravels in which the percentage is one or less, or else by mining, crushing and dressing ore in which it ranges from 1.5 to 3 per cent. The tin-bearing gravels represent a concentration from much leaner dissemination in the parent veins and granite. Aluminum ores yield as sold about 30 per cent. of the metal. This is an enrichment as compared with the rocks, though not so striking a one as in the case of other metals. But the great change necessary in aluminum is in the method of combination. It is so tightly locked up in silicates in the rocks as to preclude direct extraction by any known method.

Nickel needs to be present in amounts of several per cent., say two to five, and occurs either alone or with copper. Cobalt is always with it in small amounts. Platinum occurs in exceedingly small percentages. It is almost all obtained from gravels in Russia, and the gravels yielded in 1899 according to C. W. Purington about forty cents to the yard, platinum being quoted in that year at $15 to $18 per ounce. There was, therefore, in the gravels about one fortieth ounce in the yard, or one sixtieth in a ton or about 5.5 hundred thousandths of a per cent. Platinum in some rocks has been found in amounts of one twentieth to one half ounce, or from 16 hundred thousandths to 16 ten thousandths of one per cent., but they are rare and peculiar types.

In order to be salable manganese ores of themselves must yield about 50 per cent., but if iron is also present they may be as low as 40. Chromium has but one ore, and it must contain about 40 per cent. Of antimony, arsenic and cobalt it is hardly possible to speak, since, except perhaps in the case of the first, they are unimportant by-products in the metallurgy of other ores.

In summary it may be stated that in the ores the metals must be present in the following amounts.

	Percentage in Ores.	Ounces to Ton.	Percentage in Earth's Crust.
Iron,	35–65		4.71
Copper,	2–10		.0000X
Lead,	7–50		.0000X
Zinc,	25–60		.0000X
Silver,	1/12–1/150	2–25	.000000X
Gold,	1/300–1/6,000	1/20–1	.0000000X
Tin,	1–3		.000X–.0000X
Aluminum,	30		8.13
Nickel,	2–5		.01
Manganese,	50		.07
Chromium,	40		.01

We now have before us some fundamental conceptions from which as a point of departure we may set out upon the real discussion of the subject. We understand the gross composition of the outer earth; we have some idea of the quantitative distribution of the metals in the rocks, especially in the richer instances; finally we have seen the extent to which they must be

concentrated in order that they may be objects of mining. The next step is to establish first the agent or solvent which can effect the collection of the sparsely distributed metals, and second the places where the precipitation of them takes place. We may then inquire more particularly into the source of the agent and the methods of its operation. In order to do this in the time at command I must remorselessly focus attention on the large and essential features, resolutely avoiding every side issue or minor point, however inviting.

The one solvent which is sufficiently abundant is water, and practically all observers are agreed that for the vast majority of ore deposits it has been the vehicle of concentration. Of course it need not operate alone. On the contrary easily dissolved and ever present materials like alkalies may, and undoubtedly do, increase its efficiency. It does not operate necessarily as cold water. On the contrary, we all know that the earth grows hotter as we go down, so that descending waters could not go far without feeling this influence. Volcanoes, too, indicate to us that there are localities where heat is developed in enormous amounts and not far below the surface. There is, therefore, no lack of heat and we need only be familiar with the western country to know that there is no lack of hot springs when we take a comprehensive view. As solvents, hot waters are so incomparably superior to cold waters that they appeal to us strongly. We may, therefore, take it as well established that water is the vehicle. The chemical compounds which constitute the ores naturally differ widely in solubility and no sweeping statements can be made regarding them. Iron, for example, yields very soluble salts and is widely, one might almost say universally distributed in ordinary waters. Its ores are compounds of the metal with oxygen and in this respect it differs from nearly all others, which are mostly combined with sulphur. Although almost all of them have oxidized compounds, the latter are on the whole very subordinate contributors to our furnaces.

Iron is everywhere present in the rocks and when exposed to the natural reagents it is one of their most vulnerable elements. It, therefore, presents few difficulties in the way of solution and

concentration by waters which circulate on or near the surface and which perform their reactions under our eyes.

The compounds of copper, lead, zinc, silver, nickel, cobalt quicksilver, antimony and arsenic with sulphur present more difficult problems and ones into whose chemistry it is impossible to enter here in any thorough way, but in general it may be said that the solutions were probably hot, that they were in some cases alkaline, in others acid, and that the pressure under which they took up the metals in the depths has been an important factor in the process. The loss of heat and pressure as they rose toward the surface no doubt aided in an important way in the result.

The first condition for the production of an ore-deposit is a water way. It may be a small crack; or a large fracture; or a porous stratum, but in some such form it must exist. Naturally porous rock affords the simplest case, and provides an easily understood place of precipitation. For example in the decade of the seventies rather large mines at Silver Reef in southern Utah were based upon an open-textured sandstone into which and along certain lines, silver bearing solutions had entered. Wherever they met a fossil leaf or an old stick of wood which had been buried in the rock the dissolved silver was precipitated as sulphide or chloride. Sometimes for no apparent reason the solutions impregnated the rock with ore, but the ore seems to follow along certain lines of fracturing. Again at Silver Cliff near Rosita in central Colorado, the silver solutions had evidently at one time soaked through a bed of porous volcanic ash, and had impregnated it with ore, which while it lasted, was quarried out like so much rock. In the copper district of Keweenaw Point on Lake Superior, the copper bearing solutions have penetrated in some places an old gravel bed and impregnated it with copper; in other places they have passed along certain courses in vesicular lava flows, and have yielded up to the cavities, scales and shots of native copper.

It has happened at times that the ore-bearing solutions, rising through some crevice have met a stratum charged with lime, and having spread sideways have apparently been robbed of their metals because the lime precipitated the valuable minerals. In

the Black Hills of South Dakota, there are sandstones with beds of calcareous mud rocks in them. Solutions bringing gold have come up through insignificant-looking crevices called " verticals " and have impregnated these mud rocks with long shoots of valuable gold ores. In prospecting in a promising locality the miner, knowing the systematic arrangement of the verticals, and having found the lime-shales, drifts along in them, following a crevice in the hope of breaking into ore. The very extended and productive shoots of lead-silver ores at Leadville, Colo., which have been vigorously and continuously mined since 1877, are found in limestone and usually just underneath sheets of a relatively impervious eruptive rock. They run for long distances and suggest uprising solutions which followed along beneath the eruptive, perhaps checked by it, so that they have replaced the limestone with ore. The limestone must have been a vigorous precipitant of the metallic minerals.

The fracture itself up through which the waters rise may be of considerable size and thus furnish a resting place for the ore and gangue as the associated barren mineral is called. A deposit then results which affords a typical fissure vein. The commonest filling is quartz, but at times a large variety of minerals may be present and sometimes in beautifully symmetrical arrangement. In the latter case the uprising waters have first coated each wall with a layer. They have then changed in composition and have deposited a later and different one and so on until the crack has become filled. Often cavities are left at the center or sides and are lined with beautiful and shining crystals, which flash and sparkle in the rays of a lamp, like so many gems. There are quartz veins in California which are mined for gold and which seem to have filled clean-cut crevices, wall to wall, for several feet across. More often there is evidence of decided chemical action upon the walls, which may be impregnated with the ore and gangue for some distance away from the fissure. As the source of supply is left, however, the impregnation becomes less and less rich, and finally fades out into barren wall-rock. The enrichment of the walls varies also from point to point, since where the rock is tight the solutions can not spread laterally, but

where it is open the impregnation may be extensive. The miner has, therefore, to allow for swells and pinches in his ore.

Of even greater significance than the lateral enrichment is the peculiar arrangement of the valuable ore in a vein that may itself be continuous for long distances although in most places too barren for mining. Cases are, indeed, known in which profitable vein matter has been taken out continuously for perhaps a mile along the strike, but they are relatively rare. The usual experience reveals the ore running diagonally down in the vein filling, and more often than not following the polished grooves in the walls which are called slickensides, and which indicate the direction taken by one wall when it moved on the other during the formation of the fracture. The rich places may terminate in depth as well, and again may be repeated, but they must be anticipated, and for them allowance must be made in any mining operation.

Ores, therefore, gather along subterranean water-ways. They may fill clean-cut fissures, wall to wall; they may impregnate porous wall rocks on either side, they may even entirely replace soluble rocks like limestones.

We may now raise the question as to the source of the water which accomplishes these results and the further question as to the cause of its circulations.

The nature of the underground waters which are instrumental in filling the veins, presents one of the most interesting, if not the most interesting, phase of the problem and one upon which attention has been especially concentrated in later years. The crucial point of the discussion relates to the relative importance of the two kinds of ground-waters, the magmatic, or those from the molten igneous rocks and the meteoric or those derived from the rains. The magmatic waters are not phenomena of the daily life and observation of the great majority of civilized peoples, and for this reason they have not received the attention that otherwise would have fallen to their share. Relatively few geologists have the opportunity to view volcanoes in active eruption, and have but disproportionate conceptions of the clouds and clouds of watery vapor which they emit. The enormous volume

has, however, been brought home to us in recent years, with great force, by the outbreak of Mont Pelée, and we of this academy, thanks to the efforts of our fellow-member, Dr. E. O. Hovey, of the American Museum of Natural History, have had them placed very vividly before us. It is on the whole not surprising that to the meteoric waters most observers in the past have turned for the chief, if not the only, agent. I will, therefore, first present as fully as the time admits and as fairly as I may, this older view which still has perhaps the larger number of adherents.

Except in the arid districts rain falls more or less copiously upon the surface of the earth. The largest portion of it runs off in the rivers; the smallest portion evaporates while on the surface, and the intermediate part sinks into the ground, urged on by gravity, and joins the ground-waters. Where crevices of considerable cross-section exist, they conduct the water below in relatively large quantity. Shattered or porous rock will do the same and we know that open-textured sandstones dipping down from their outcrops and flattening in depth lead water to artesian reservoirs in vast quantity. As passages and crevices grow smaller, the friction on the walls increases and the water moves with greater and greater difficulty. When the passage grows very small, movement practically ceases. The flow of water through pipes is a very old matter of investigation, and all engineers who deal with problems of water supply for cities or with the circulation of water for any of its countless applications in daily life must be familiar with its laws. Friction is such an important factor that only by the larger natural crevices can the meteoric waters move downward in any important quantity or with appreciable velocity. They do sink, of course, and come to comparative rest at greater or less distance from the surface and yield the supplies of underground water upon which we draw.

The section of the rocks which stands between the surface and the groundwater is the arena of active change and is that part of the earth's crust in which the meteoric waters exercise their greatest effect. Rocks within this zone are in constant process of decay and disintegration. Oxidation, involving the production of sulphuric acid from the natural metallic sulphides is ac-

tively in progress. Carbonic acid enters also with the meteoric waters. The rocks are open in texture and favorably situated for maximum change. From this zone we can well imagine that all the finely divided metallic particles which are widely and sparsely distributed in the rocks go into solution and tend to migrate downward into the quiet and relatively motionless ground-water. If the acid solutions escape the precipitating action of some alkaline reagent such as limestone they may even reach the ground-waters, and their dissolved burdens may be contributed to this reservoir, but the greater portion seems to be deposited at the level of the ground-water itself or at moderate distances below it. Impressed by these phenomena which present a true cause of solution, and influenced by their familiar and every day character, we may build up on the basis of them a general conception of the source of the metallic minerals dissolved in those aqueous solutions which are recognized by all to be the agents for the filling of the veins.

Let us now focus attention on the ground-water. This saturates the rocks, fills the crevices and forces the miner who sinks his shaft, to pump, much against his natural inclination. The vast majority of mines are of no great depth, and the natural conclusion of our earlier observers, based on this experience, has been that the ground-waters extend downward saturating the strata of the earth to the limit of possible cavities, distances which vary from 1,000 to more than 30,000 feet. To this must be added another familiar phenomenon. The interior temperature of the earth increases at a fairly definite ratio of about one degree Fahrenheit for each 60–100 feet of descent. In round numbers, if we start with a place of the climatic conditions of New York—that is, with a mean annual temperature of about 51°, we should on descending 10,000 feet below the surface find a temperature of about 212°, and if we go still deeper, it would be still greater. Of course, under the burden of the overlying column of water, the actual boiling points for the several depths would be greater, and it is a question whether the increase of temperature would overcome the increase of pressure and the consequent rise of the boiling point so as to convert this water into steam, cause great

increase in its elasticity, decrease in its specific gravity and thereby promote circulations. At all events, the rise in temperature would cause expansion of the liquid, would disturb equilibrium and to this degree would promote circulations.

There is one other possible motive power. The meteoric waters enter the rocky strata of the globe at elevated points, sink downward, meet the ground-water at altitudes above the neighboring valleys and establish thereby what we call head. In consequence they often yield springs. If we imagine the head to be effective to considerable depths we have again the deep-seated waters under pressure, which after their long and devious journey through the rocks may cause them to rise elsewhere as springs. The head may in small degree be aided by the expansion of the uprising heated column whose specific gravity is thereby lowered as compared with the descending colder column.

May we now draw all these facts and supposed or assumed phenomena into one whole?

The descending meteoric waters become charged with dissolved earthy and metallic minerals in their downward, their deep-seated lateral and perhaps also at the beginning of their heated uprising journey. They are urged on by the head of the longer and colder descending column and by the interior heat. They gather together from many smaller channels into larger issuing trunk channels. They rise from regions of heat and pressure which favor solution, into colder regions of precipitation and crystallization. They deposit in these upper zones their burden of dissolved metallic and earthy minerals and yield thus the veins from which the miner draws his ore.

This conception is based on phenomena of which the greater part are the results of everyday experience. It is attractive, reasonable and is on the whole the one which has been most trusted in the past. Doubtless it has the widest circle of adherents today. It is, however, open to certain grave objections which are gaining slow but certain support.

The conception of the extent of the ground-water in depth, for example, is flatly opposed to our experience in those hitherto few but yearly increasing deep mines which go below 1,500 or 2,000

feet. Wherever deep shafts are located in regions other than those of expiring but not dead volcanic action, they have passed *through* the ground-water and if this is carefully impounded in the upper levels of the mines and not allowed to follow the workings downward, it is found that there is not only less and less water but that the deep levels are often dry and dusty. Along this line of investigation, Mr. John W. Finch, recently the State Geologist of Colorado, has reached the conclusion after wide experience with deep mines that the ground-waters are limited, in the usual experience, to about 1,000 feet from the surface and that only the upper layer of this is in motion and available for springs.

Artesian wells do extend in many cases to depths much greater than this and bring supplies of water to the surface, but their very existence implies waters impounded and in a state of rest.

To this objection that the ground-waters are shallow it has been replied that when the veins were being formed the rocks were open-textured and admitted of circulation, but subsequently the cavities and waterways became plugged by the deposition of minerals by a process technically called cementation and the supply being cut off, they now appear dry. There must, however, in order to make " the head " effective have once been a continuous column of water which introduced the materials for cementation. It is at least difficult to understand how a process, which could only progress by the introduction of material in very dilute solution should by the agency of crystallization drive out the only means of its production. Some residue of water must necessarily remain locked up in the partially cemented rock. This residue we, of course, do not find where rocks are dry and drifts are dusty. In many cases also where deep cross-cuts have penetrated the fresh wall-rock of mines, cementation if present has been so slight as to escape detection.

If we once admit that this conclusion is well based, it removes the very foundation from beneath the conception of the meteoric waters and tumbles the whole structure in a heap of ruins.

While I would not wish to positively make so sweeping a statement as this about a question involving so many uncertainties,

there is nevertheless a growing conviction among a not inconsiderable group of geologists that the rocky crust of the earth is much tighter and less open to the passage of descending waters than has been generally believed; and that the phenomena of springs which have so much influenced conclusions in the past, affect only a comparatively shallow, overlying section. Such phenomena of cementation as we see are probably in large part due to the action of water stored up by the sediments when originally deposited and carried down by them with burial. Under pressure a relatively small amount of water may be an important vehicle for recrystallization.

It has been assumed in the above presentation of the case of the meteoric waters that they are able to leach out of the deep-seated wall rocks the finely disseminated particles of the metallic minerals, but the conviction has been growing in my own mind that we have been inclined to overrate the probability of this action in our discussions. In the first place our knowledge of the presence of the metals in the rocks themselves is based upon the assay of samples almost always gathered from exposures in mining districts. The rock has been sought in as fresh and unaltered a condition as possible and endeavors have been made to guard against the possible introduction of the metallic contents by those same waters which have filled the neighboring veins. But if we admit or assume that the assay values are original in the rock; and, in case the latter is igneous, if we believe that the metallic minerals have crystallized out with the other bases from the molten magma, we are yet confronted with the fact that their very presence and detection in the rock shows that they have escaped leaching even though they occur in a district where underground circulations have been especially active. From the results which we have in hand, it is quite as justifiable to argue that the metals in the rocks are proof against the leaching action of underground circulations as that they fall victims to it. These considerations tend to restrict the activities of the meteoric waters to the *vadose* region as Pošepnỳ calls it, *i. e.,* that belt of the rocks which stands between the permanent water-level and the surface. Within it is an active area of solution, as we have all

recognized for many years, but, as previously stated, experience shows that the metals which go into solution in it strongly tend to precipitate at or not far below the water-level itself.

It is of interest, however, to seek some quantitative expression of the problem and the assays given above furnish the necessary data.

I have taken the values of the several metals which have been found by the assays of what were in most cases believed to be normal wall rocks, selecting those of igneous nature because experience shows them to be the richest. The percentages have been turned into pounds of the metal per ton of rock; this latter value has then been recast into pounds of the most probable natural compound or mineral in each case. I have next calculated the volume of a cube corresponding to the last weight, and by extracting its cube root have found the length of the edge of such cube. If now we assume a rock of a specific gravity of 2.70 which is a fair average value, and allow it 11 to 12 cubic feet to the ton, or say 20,000 cubic inches, the edge of the cube-ton will be 27.14 inches. The ratio of the edge of the cube of metallic mineral to the edge of the cube-ton of enclosing rock, will give us an idea of the chance that a crack large enough to form a solution-water-way will have of intersecting that amount of contained metallic mineral. Of course in endeavoring to establish this quantitative conception I realize that the metallic mineral is not in one cube, and that through a cube-ton of rock more than one crack passes, but I assume that the fineness of division of the metallic mineral practically keeps pace with the lessening width and close spacing of the crevices. It is also realized that the shape of the minerals is not cubical. I am convinced from microscopic study of rocks and the small size of the metallic particles that their subdivision certainly keeps pace with any conceivable solution-cracks, and that no great error is involved in the first assumption made. The sides of a cube represent three planes which intersect at right angles and which are mathematically equivalent to any series of planes intersecting at oblique angles. Hence if we consider as cubes the subdivisions formed in our rock mass by any series of intersecting cracks,

there are three sets of planes, any one of which might intersect the cube of ore. We must, therefore, multiply the ratio of probability that any single set will intersect it by three in order to have the correct expression. The chance that a crack, of the width of the cubic edge of the enclosed mineral, will strike that cube is given by the ratios in the last column, which ratios I assume hold good with increasing fineness of subdivision both of metallic minerals and of cracks.

	Per Cent. by Analysis.	Pounds per Ton.	Pounds Chalcopyrite.	Volume Cu. In.	Edge of Cube.	Ratio of Edge to Edge of Cube ton Rock.	Ratio of Probability.
Copper.	.009	.18	.52	3.42	1.5	1/18	1/6
			Galena.				
Lead.	.0011	.022	.025	.092	.45	1/60	1/20
	.008	.16	.186	.700	.89	1/31	1/10
	.004	.08	.002	.340	.70	1/39	1/13
			Zincblende.				
Zinc.	.0048	.096	.128	.90	.97	1/35	1/12
	.009	.180	.240	1.60	1.17	1/21	1/7
			Argentite.				
Silver.	.00007	.0014	.0016	.006	.18	1/148	1/49
	.00016	.0032	.0037	.014	.24	1/113	1/38
			Gold.				
Gold.	.00002	.0004	.0004	.00065	.086	1/313	1/104
	.00004	.0008	.0008	.00130	.109	1/249	1/83

From the table it is evident that the chances vary from a maximum in the case of copper of one in six through various intermediate values to a minimum for gold of one in over one hundred. This is equivalent to saying that with cracks whose total width bears the same relation to the width of the rock mass as is borne by the diameter of the particle of ore, the chance of crossing a particle varies from one in six to one in one hundred. Or we may say that with cracks of this spacing from one sixth to one one-hundredth of the contained metallic mineral might be leached out.[1] When, therefore, as is often the case in monographs upon

[1] With regard to the flow of waters through crevices and the relation of the flow to varying diameters or widths, a very lucid statement will be found

the geology of a mining district, inferences are drawn as to the possibility of deriving the ore of a vein by the leaching of wall-rocks whose metallic contents have been proved by assay, the total available contents ought to be divided by a number from six to one hundred if the above reasoning is correct. This diminution will tend to modify in an important manner our belief in the probability of such processes as have been hitherto advocated. We may justly raise the following questions. How closely set, as a matter of fact, are the cracks which are large enough to furnish solution water-ways in the above rocks, and can we reach any definite conception regarding their distribution? Some quantitative idea of the relations may be obtained from the tests of the recorded absorptive capacity of the igneous rocks which are employed as building stone. G. P. Merrill in his valuable work on "Stones for Building and Decoration," pp. 459, has given these values for 33 granites and 4 diabases and gabbros. They vary for the granites from a maximum of one twentieth to a minimum of one seven hundred and fourth. I have averaged them all and have obtained one two hundred and thirty-seventh as the result. That is, if we take a cubic inch of granite and thoroughly dry it, it will absorb water up to one two hundred and thirty-seventh of its weight. The volume of this water indicates the open spaces or voids in the stone. The average of the specific gravities of the 33 granites is 2.647. If, by the aid of this value we turn our weight of water into volume we find that its volume is one-ninetieth that of the rock. For the four diabases and gabbros, similarly treated, the ratio of absorption is one three hundred and tenth; the specific gravity is 2.776 and the ratio of volume one one hundred and tenth. We can express all this more intelligibly by saying that, if we assume a cube of granite and if we combine all its cavities into one crack passing through it, parallel to one of its sides, the width of the crack will be to the edge of the cube, as 1 to 90. In the diabases and gabbros, similarly treated, the ratio will be 1 to 110. These

in President C. R. Van Hise's valuable paper in the *Transactions of the American Institute of Mining Engineers,* XXX., 41, and in his Monograph on Metamorphism.

values are very nearly the same as the average of the ratios of the edges of the cubes of rock and ore given in the table on p. 226, it being 1 to 104. We may conclude, therefore, that in so far as we can check the previous conclusion by experimental data it is not far from the truth.

It may be stated that the porphyritic igneous rocks which have furnished nearly all the samples for the above analyses, are as a rule extremely dense, and that their absorptive capacity is more nearly that of the compact granites than the open textured ones. It is highly improbable that underground water circulates through these rocks to any appreciable degree except along cracks which have been produced in the mechanical way, either by contraction in cooling and crystallizing; or by faulting and earth movements. The cracks from faulting are very limited in extent and in the greater number of our mining districts they affect but narrow belts, small fractions of the total. Of the cracks from cooling and crystallizing those of us who have seen rock faces in cross-cuts and drifts underground, where excavations have been driven away from the veins proper, can form some idea, if we eliminate the shattering due to blasting. My own impression is that in rocks a thousand feet or so below the surface such cracks are rather widely spaced, and that, when checked in a general way by the ratios just given, these rocks are decidedly unfavorable materials from which the slowly moving meteoric ground-waters (if such exist) may extract such limited and finely distributed contents of the metals.

I have also endeavored to check the conclusions by the recorded experience in cyaniding gold ores in which fine crushing is so important, and I can not resist the conviction that we have been inclined to believe the leaching of compact and subterranean masses of rock a much easier and more probable process than the attainable data warrant.

As soon, however, as we deal with the open-textured fragmental sediments and volcanic tuffs and breccias the permeability is so enhanced as to make their leaching a comparatively simple matter. Yet so far as the available data go, they are poor in the metals or else are open to the suspicion of secondary impreg-

nation. They certainly have been seldom, if ever, selected by students of mining regions as the probable source of the metals in the veins.

Should the above objections to the efficiency of the meteoric waters seem to be well established, or at least to have weight, it follows that the arena where they are most, if not chiefly, effective is the vadose region, between the surface and the level of the ground-water. Undoubtedly from this section they take the metals into solution and carry them down. But it is equally true that they lose a large part of this burden, especially in the case of copper, lead and zinc, at or near the level of the ground-water and are particularly efficient in the secondary enrichment of already formed but comparatively lean ore-bodies.

Let us now turn to the magmatic waters. That the floods of lava which reach the surface are heavily charged with them, there is no doubt. So heavily charged are they, that Professor Edouard Suess, of Vienna, and our fellow-member, Professor Robert T. Hill, of New York, have seen reason for the conclusion that even the oceanic waters have in the earlier stages of the earth's history been derived from volcanoes rather than, in accordance with the old belief, volcanoes derive their steam from downward percolating sea-water. From vents like Mont Pelée which in periods of explosive outbreaks yield no molten lava, the vapors rise in such volume that cubic miles become our standards of measurement.

There is no reason to believe that many of the igneous rocks which do not reach the surface are any less rich, and when they rise so near to the upper world that their emissions may attain the surface, we must assign to the resulting waters a very important part in the underground economy.

This general question has attracted more attention in Europe in recent years as regards hot springs than in America. So many health resorts and watering places are located upon them that they are very important foundations of local institutions and profitable enterprises. Professor Suess, whom I have earlier cited, delivered an address a few years ago at an anniversary celebration in Carlsbad, Bohemia, in which he maintained that

in the Carlsbad district the natural catchment basin was insufficient to supply the waters and that both the unvarying composition and amount through wet seasons and dry were opposed to a meteoric source. Water, therefore, from subterranean igneous rocks, well-known to exist in the locality, was believed to be the source of the springs. The same general line of investigation has led Dr. Rudolf Delkeskamp, of Giessen, and other observers to similar conclusions for additional springs, so that magmatic waters have assumed a prominence in this respect which leaves little doubt as to their actual development and importance.

All familiar with western and southwestern mining regions know as a matter of experience, that the metalliferous veins are almost always associated with intrusive rocks, and that in very many cases the period of ore formation can be shown to have followed hard upon the entrance of the eruptive. The conclusion has, therefore, been natural and inevitable that the magmatic waters have been, if not the sole vehicle of introduction, yet the preponderating one.

With regard to their emission from the cooling and crystallizing mass of molten material we are not, perhaps, entirely clear or well established in our thought. So long as the mass is at high temperatures the water is potentially present as dissociated hydrogen and oxygen. We are not well informed as to just what is the chemical behavior of these gases with regard to the elements of the metallic minerals. Hydrochloric acid gas is certainly a widely distributed associate. If, as seems probable, these gases can serve, alone or with other elements, as vehicles for the removal of the constituents of the ores and the gangue, the possibilities of ubiquitous egress are best while the igneous rock is entirely, or largely molten. In part even the phenomena of crystallization of the rock-forming minerals themselves may be occasioned by the loss of the dissolved gases. Through molten and still fluid rock the gases might bubble outward if the pressure were insufficient to restrain them and would, were their chemical powers sufficient, have opportunity to take up even sparsely distributed metals.

On the other hand if their emission, as seems more probable,

is in largest part a function of the stage of solidification and takes place gradually while the mass is congealing, or soon thereafter, then they must depart along crevices and openings whose ratio to the entire mass would be similar to those given above. They might have, and probably do have, an enhanced ability to dissolve out in a searching and thorough manner the finely distributed metallic particles as compared with relatively cold meteoric waters which might later permeate the rock, but as regards the problem of leaching, the general relations of crevices to mass are much the same for both, and it holds also true that the discovery of the metals by assay of igneous rocks proves that all the original contents have not been taken, by either process.

We may, however, consider an igneous mass of rock as the source of the water even if not of the ores and gangue, and then we have a well established reservoir for this solvent in a highly heated condition and at the necessary depths within the earth. Both from its parent mass and from the overlying rocks traversed by it, it may take the metals and gangue.

In the upward and especially in the closing journey, meteoric waters may mingle with the magmatic, and as temperatures and pressures fall, the precipitation of dissolved burdens takes place and our ore-bodies are believed to result. Gradually the source of water and its store of energy become exhausted; circulations die out and the period of vein-formation, comparatively brief, geologically speaking, closes. Secondary enrichment through the agency of the meteoric waters alone remains to influence the character of the deposit of ore. In brief, and so far as the process of formation of our veins in the western mining districts is concerned this is the conception which has been gaining adherents year by year and which, on the whole, most fully accords with our observed geologic relations. It accords with them, I may add, in several other important particulars upon which I have not time to dwell.

In closing I may state, that speculative and uncertain as our solution of the problem of the metalliferous veins may seem, it yet is involved in a most important way with the practical opening of the veins and with our anticipations for the future pro-

duction of the metals. Every intelligent manager, superintendent or engineer must plan the development work of his mine with some conception of the way in which his ore-body originated, and even if he alternates or lets his mind play lightly from waters meteoric to waters magmatic, over this problem he must ponder. On its scientific side and to an active and reflective mind it is no drawback that the problem is yet in some respects elusive and that its solution is not yet a matter of mathematical demonstration. In science the solved problems lose their interest; it is the undecided ones that attract and call for all the resources which the investigator can bring to bear upon them. Among those problems which are of great practical importance, which enter in a far-reaching way into our national life and which irresistibly rivet the attention of the observer, there is none with which the problem of the metalliferous veins suffers by comparison.

STRUCTURAL RELATIONS OF THE WISCONSIN ZINC AND LEAD DEPOSITS.[1]

ULYSSES SHERMAN GRANT.

INTRODUCTION.

The zinc and lead region of Wisconsin lies in the southwestern corner of that state and is included in Grant, Lafayette and Iowa counties. It is part, and the most important part, of the Upper Mississippi Valley zinc and lead district, in which mining for lead was begun over one hundred years ago. Considerably later zinc mining became important, but there was a decline in the production of the ores of both metals in the last part of the nineteenth century. During the last four years, however, there has been a marked revival of the mining industry in this district. This is due mainly to the appreciation by mining men of the existence, below the level of ground water, of important bodies of zinc sulphide. The opening up of such ore bodies, their mining and concentration by more modern methods than were formerly used, and the recent advance in prices of both zinc and lead have combined to bring this district again into notice as an active producer of these metals, but more especially of zinc.

GENERAL GEOLOGY.

The strata of this region consist of a series of limestones (or dolomites), sandstones and shales of early Paleozoic age, underlain by crystalline rocks of more ancient date, and overlain locally by loess, alluvium and residual soil. No igneous rocks of later date than the Pre-Cambrian occur, and the ore deposits bear no relation to these igneous rocks. The Pre-Cambrian does not outcrop in the region, being known here only from well drillings,

[1] The results here presented are due to detailed mapping of selected areas in the Wisconsin zinc and lead field. This mapping was carried on in 1903 and 1904 by the Wisconsin Geological and Natural History Survey; these maps will appear in Bulletin No. XIV. (now in press) of that survey.

and the glacial drift is absent, the region being within the Driftless area.

The formations represented are shown in the accompanying table, in which the approximate average thickness of each is given. The important ore deposits occur in the Galena and Platteville limestones, and these two formations comprise the surface rock over large parts of the region.

FORMATIONS OF THE WISCONSIN ZINC AND LEAD REGION.

		Feet.
PLEISTOCENE	Loess, alluvium and soil	7
SILURIAN	Niagara limestone	50
ORDOVICIAN	Maquoketa shale	160
	Galena limestone	230
	Platteville limestone	55
	St. Peter sandstone	70
	Lower Magnesian limestone	200
CAMBRIAN	Potsdam sandstone	700
PRE-CAMBRIAN	Crystalline rocks	—

The Galena formation consists of a heavily bedded, impure dolomite, the impurities being chiefly argillaceous and siliceous material, the latter commonly in the form of flint nodules. Near the base of the formation the beds are at times thinner and commonly carry a few narrow shale bands, and at the very base is a layer of carbonaceous shale known locally as "oil rock." This is from a few inches to four feet in thickness, and varies in color from chocolate to black, the former being more common. Immediately underlying the oil rock is the Platteville limestone whose upper member (ten to twenty feet in thickness) is made up of varying bands of shale, or clay, and limestone. Commonly immediately below the oil rock is a layer of gray to blue clay, or shale, from two inches to five feet in thickness. Below this are beds of a fine grained, compact limestone, known locally as "glass rock," and still lower is another shale bed. In the eastern part of the region the glass rock becomes thicker and more dolomitic in character, and the shale which underlies it is commonly carbonaceous, closely resembling the oil rock at the base of the Galena limestone. The importance of these beds of shale, or clay, in the formation of the ore deposits will be noted later.

Below the upper member of the Platteville limestone, which has just been described, this formation consists of thin bedded limestone with thicker bedded, magnesian limestone near the base.

THE ORE DEPOSITS.

The ores below the level of ground water consist of galena, sphalerite and iron sulphide, the latter commonly in the form of marcasite. Above this level are galena, smithsonite and limonite. The earlier mining in the region was confined mainly to the ores in the oxidized zone, while the mines working to-day are almost entirely below the level of ground water. The ores occur in crevices in the dolomite, or in disseminated particles in certain beds. Where the ores occur in crevices they are usually arranged in the following order, from the wall rock towards the center of the veins: (1) marcasite, (2) sphalerite with some galena, (3) galena in large crystals. In the deepest parts of the mines the third layer is commonly lacking.

The chief deposits of the region mined to-day are those which exist in the forms of flats and pitches, the flats being essentially horizontal deposits along the bedding planes of the rocks, while the pitches are dipping crevices. This peculiar form of deposit is very characteristic of the district, and is illustrated in the accompanying diagram (Fig. 12).

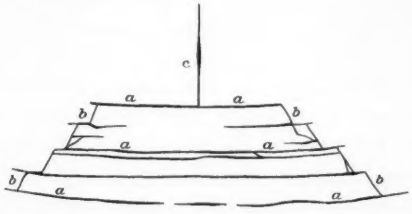


FIG. 12 Diagrammatic cross-section of flats and pitches. *a*, flats; *b*, pitches; *c*, vertical crevice.

The chief ore deposits of the region lie in the lower part (mainly the lower fifty feet) of the Galena limestone, where these flats and pitches occur. Higher up in this formation the ore

occurs in vertical crevices and in irregular openings. Near the base of the Galena there are sometimes flats which are not clearly connected with pitches. Such flats lie just above the oil rock and, while frequently in actual horizontal cavities, still pass gradually into disseminated deposits. In certain parts of the region, as at Mifflin and Dodgeville, these flats become of much importance and a number of the mines get their ores from such horizontal deposits, which occur in two forms: first, as flats which lie (1) just above the oil rock at the base of the Galena formation, and (2) in the lower part of the glass rock and just above a layer of carbonaceous shale in the Platteville formation; and second, as horizontal disseminated deposits which lie (1) in the same position as the flats just noted, and (2) actually in the oil rock or in the clay just beneath this.

STRUCTURAL GEOLOGY.

Broadly speaking, the rocks of the region dip at a very low angle towards the south-southwest, descending about twenty feet per mile. The strata have, in addition to this gentle dip, been compressed into very open folds whose axes trend east and west; and a still more open folding, not commonly apparent, has taken place at right angles to the first. The east-west folds are of two types: first, those whose limbs are approximately equal, and second, those anticlines whose south limbs are long and gently sloping, while the north limbs are shorter and steeper. In addition to these there are some small, gentle monoclinal folds dipping toward the south. Careful mapping of certain parts of the region—parts selected because they contain important ore deposits—and the construction on the maps of structural contour lines on the base of the Galena formation, have brought out a number of these small east-west anticlines and synclines, and the still more important fact that many of the ore deposits lie in these shallow synclinal basins. This relation of the deposits to structural basins is shown in Figs. 13, 14 and 15. The first of these represents a simple case of disseminated deposits which lie along the Little Platte River, about three miles west of Platteville. The ore here exists in the bottom layer of the Galena dolomite and in

the oil rock and the blue shale which immediately underlies the oil rock. The synclinal nature of the basin is very apparent and the chief deposits, *i. e.*, at the Graham and Stevens mine and at the Capitola mine, lie along the axis of the basin.

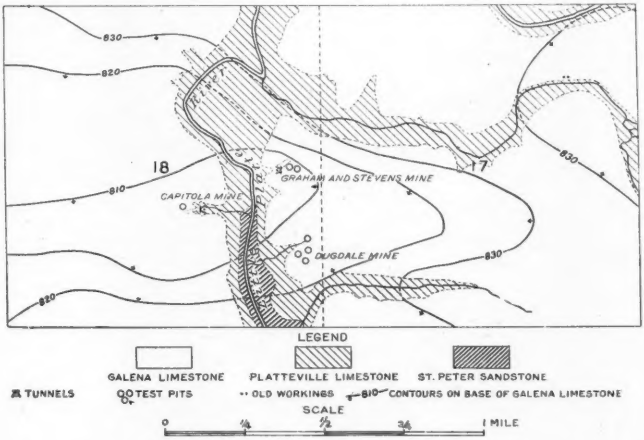


FIG. 13. Map of sections 17 and 18, T. 3. N., R. I. W., Grant County, Wisconsin. Arrows show the direction of dip of the rocks. Where contour lines are of dashes the Galena limestone has been removed by erosion.

In Fig. 14 is shown a map of the workings in the vicinity of Highland, one of the most thoroughly exploited camps in the region. Here the main ores have come from a small area in Sec. 28, and the broad synclinal nature of the basin in which these ores occur is brought out clearly by the map. It is not at all improbable that more detailed information would show that in the vicinity of the Lewis mine the structural contours should swing more to the northward, making that mine lie in a subordinate north-south syncline.

Fig. 15 shows the mines in the vicinity of Linden. One of these, the Mason, has been, and is still, a large producer of ore, and is situated near the axis of the syncline, while the Glanville and the Milwaukee mines are practically on the axis. To the north of these mines there is a subordinate syncline which holds

the Robarts mine, at the present time one of the important producers of lead.

Some other localities in which mines are situated in synclinal basins are as follows: the Ellsworth, Sun Rise, and Sun Set

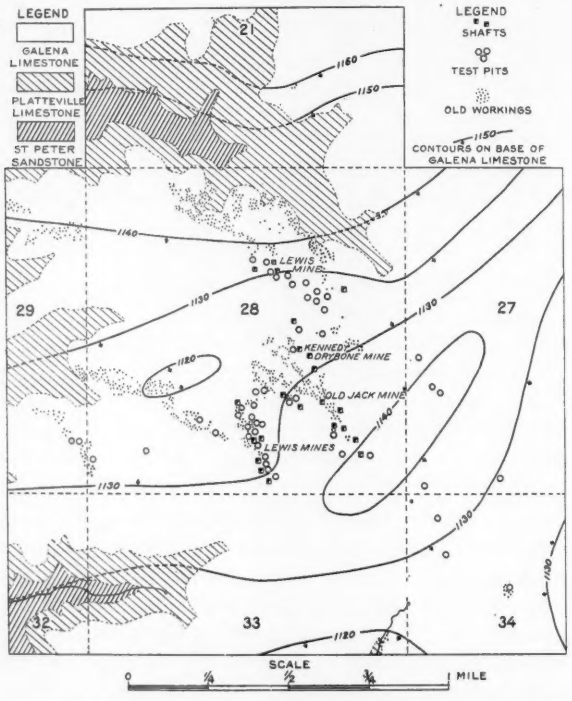


FIG. 14. Map of vicinity of Highland, Iowa County, Wisconsin. Arrows show the direction of dip of the rocks. Where contour lines are of dashes the Galena limestone has been removed by erosion.

mines, west of Mifflin; the Gruno mine at Mifflin; most of the deposits in the vicinity of Dodgeville, which lie in a broad shallow basin pitching very slightly towards the southwest. The Hoskin and Kennedy mines near Hazel Green are also in a synclinal basin, and the same is probably true of other mines about

Hazel Green, although sufficient information is not at hand to show the exact nature of the basins in these cases. The important deposits at Platteville—the Enterprise and the Empire mines—are also in a marked syncline. The Doll mine at Meekers

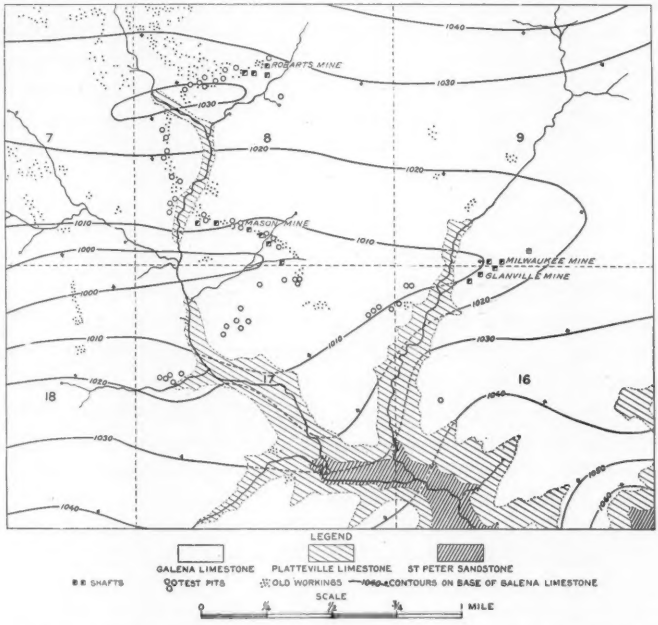


FIG. 15. Map of the vicinity of Linden, Iowa County, Wisconsin. Arrows show direction of dip of the rocks. Where contour lines are of dashes the Galena limestone has been removed by erosion.

Grove is in the same kind of basin, while the Trego, Raisbeck and Gritty Six mines at Meekers Grove are on the north limb of a rapidly dipping anticline. The exact relation of these deposits to structure is not clear, but it is not unlikely that they lie in subordinate, northward plunging synclines.

Since this detailed mapping was done for the Wisconsin Geological and Natural History Survey the United States Geological

Survey has done similar mapping in the vicinity of Potosi, Wisconsin, and also at Dubuque, Iowa, and in both of these cases the main ore deposits were found to lie in synclinal basins.

It is not intended to imply that all of the deposits of the Wisconsin zinc and lead region are confined to these synclinal basins, but it is very evident that a large number of the important deposits are so located, and there can be no question as to the causal relation of these structural forms to the ore deposits. This relation was first discussed by Chamberlin in 1882,[1] but at that time the detailed information necessary to accurately locate these basins was not at hand; the recent careful mapping of the district has served to substantiate Chamberlin's conclusions.

ORIGIN OF THE BASINS.

Such shallow basins as are here described may originate in at least three different ways. In the first place, they may be due to irregularities in the sea bottom when the sediments were being deposited, or to irregularities in deposition. In the second place, they may be due to actual mechanical deformation of the rocks since the rocks were solidified. The third origin may be stated to be the vertical compression, or settling down, of certain areas which contained considerable thicknesses of carbonaceous material. This idea has been mentioned by H. Foster Bain, who suggests that the oil rock layer (containing much organic matter) was originally thicker than at present, and that in the changes which this bed has undergone it has decreased in thickness to a considerable degree, in the same manner as coal beds have decreased in thickness. If now, this bed were especially thick in certain limited localities, such a decrease in thickness would cause a sinking of the overlying rocks and would so produce one of these structural basins. In some cases it is not clear what is the origin of the basin in which any particular ore deposit may occur. Where, however, the dips are steep, as for instance in the vicinity of Meeker's Grove, there is no question that actual deformation has been the important factor in producing the basin.

[1] Geology of Wisconsin, Vol. IV., pp. 432–438.

Chamberlin[1] has shown how the peculiar crevices called flats and pitches, especially the pitches, could be produced along the bottom of the synclines by folding of the rocks. The slumping of the beds, due to the cause suggested by Bain, might also produce similar pitching crevices. If this were true it might be difficult to decide to which one of the two causes any very shallow basin containing flats and pitches was due. We should not, however, expect such pitching crevices to occur in basins due to inequalities in deposition, and as some of the basins,—especially those at Highland, at Dodgeville, and in the area illustrated in Fig. 1,—do not contain any, or at least no well marked system, or systems, of pitches, these areas may owe their basin-like character to inequalities of deposition. If such is the case we have a reasonable explanation as to why the disseminated deposits and flats without pitches are confined to certain basins, while the flats and pitches, especially the pitches, are confined to other basins.

THE ORIGIN OF THE ORES.

In the Wisconsin district it is evident that the ores owe their origin to circulating underground waters, which have taken the metallic materials from finely disseminated particles in the dolomite and concentrated them in certain positions. Synclinal basins, especially if these were pitching troughs, would form exceedingly likely places for the active circulation of these underground waters, and this circulation would be much accelerated if in such basins there were the peculiar fissures known as flats and pitches, or fissures of any other description. The evidence seems almost conclusive then, that the ores were deposited by descending solutions concentrated in and flowing along synclinal basins, these synclinal basins being bottomed by practically impervious layers of shale. These impervious layers of shale are the oil rock beds at the base of the Galena limestone and the shale, or clay, which immediately underlies this oil rock. In the eastern part of the region, where another carbonaceous shale bed is quite prominent at the base of the glass rock, we find also in this bed

[1] Geology of Wisconsin, Vol. IV., pp. 484–488.

and immediately overlying it, flats of ore and also disseminated ore.

It is probable that, if such a circulation as here described took place, the carbonaceous matter in the oil rock would precipitate the sulphides of lead, zinc and iron; and this seems clearly to have been the case in the disseminated deposits and in the flats and pitches which are immediately adjacent to the oil rock. For the precipitation of the ores in the higher crevices this cause would not seem to have been sufficient, and in this case some products from the oil rock—such as hydrogen sulphide—may be regarded as rising upward through the flats and pitches to the vertical crevices above and thus precipitating the metallic sulphides for considerable distances above the oil rock layers.

THE SCOPE OF APPLIED GEOLOGY, AND ITS PLACE IN THE TECHNICAL SCHOOL.

DOUGLAS WILSON JOHNSON.

An attempt to classify scientific work and workers may be a hazardous undertaking. At the same time, it is occasionally necessary, for the sake of clearness, to make such an attempt. In order to present certain considerations relating to applied geology, it seems best to recognize three phases of scientific work, with corresponding groups of scientific investigators, students and schools. The broad classification thus suggested appears to follow lines that are natural and easily recognized, although individual cases may present special difficulties.

Scientific research may be pursued primarily for the discovery of Nature's truths and a knowledge of the workings of her laws. There may be no attempt to obtain knowledge that will have a market value, and when finally attained the results of such research may be wholly worthless from the commercial point of view. To say that they have no *practical* value is not just, for they may possess a very high educational value, and the extension of our educational resources is a consideration of the greatest practical importance. A study of the successive stages in the development of a group of fossil shells, together with the bearing of that development on the theory of evolution, is an example of that phase of scientific research which is generally carried on without regard to the cash selling price of the knowledge obtained.

On the other hand, research may be conducted in a thoroughly scientific manner, for the solution of a definite problem presented by commercial interests, with the primary object of making great financial gains. The investigator would not spend a moment on the work did it not promise to have a certain market value. The stimulus to prolonged and patient labor, as well as the initial cause of the investigation, must be considered as financial in

character. As an example of this class of scientific research we may cite the attempts to solve the problem of economically treating titaniferous magnetite, in the hope of making the great deposits of this ore of iron available, and of securing valuable monetary returns.

Intermediate between these two classes of scientific work is that class of study carried on with a certain regard to the commercial value of the results to be obtained, but not for commercial reasons primarily; and with an enthusiastic interest in the work for its own sake, but with the requirement that the branch of work selected must have something more than a merely educative value. It is apparent that such a class of work occupies the middle ground between the purely philosophical researches on the one side, and the purely commercial investigations on the other.

Associated with these three phases of scientific work we find three groups of investigators, both students and teachers, and three classes of schools. It is one function of our large universities to encourage the best in philosophical and educational work, and to this end they maintain schools of pure science. Research along lines that promise no financial reward is provided for by endowment. Here we find most of the teachers who have an enthusiastic interest in original investigations conducted without regard to the monetary value of the results to be obtained, and here come those students who have determined to devote their lives to the study of nature's laws, even at a great financial sacrifice.

The university is not a money-making institution, however, and we should not expect to find it actively engaged in furthering investigations for the main purpose of selling the results for a large cash consideration. Accordingly we must look elsewhere for the teachers and students engaged in scientific investigations which are stimulated by commercial needs and the promises of financial gain. From the nature of the case much of this class of work is done independently by individual workers, rather than by organized schools. Large commercial enterprises sometimes justify the maintenance of research laboratories, where special

problems of immediate importance to their success are worked out by skilful investigators, and where younger assistants may get valuable training. At other times these enterprises profit by securing the services of outside workers for a limited time or for a special problem; and such workers are often teachers in the universities or technical schools, who devote the most of their time to one of the other two classes of investigation here considered.

The intermediate phase of scientific work, neither purely philosophical nor purely commercial, occupies a most important place in our educational institutions. It is not alone the function of the university to provide for philosophical and educational advancement,—it must also provide training for those men who are to take the lead in commercial enterprises. Such a training, to be most efficient, must prepare the student to take the results of the more philosophical investigations and apply them to the practical problems of every-day life. So it is that our large universities maintain technical schools, or schools of applied science, as well as schools of pure science. The same field is occupied by our various independent technical schools. In these schools we find a class of teachers who are interested in their several lines of scientific work for something more than financial reward,—else they would be occupying better paying positions in commercial concerns. Yet they must be keenly interested in the practical commercial applications of their work, for that is the side of the work which they are called upon to emphasize. To these schools come those students who look forward to a life of professional business activity, and who desire to provide themselves with the best possible equipment with which to meet the keen competition of the commercial world, hoping thereby to be successful in financial enterprises. This whole question of the application of scientific principles to the solution of practical problems is one of engrossing interest, and of paramount importance to the technical school. Certain phases of this question, especially those involving the application of geological principles, are here presented.

The term *applied science* may be so interpreted as to cover a

very wide field. As here used, the term refers to the application of the principles of the pure sciences, such as psychology, biology, geology, physics, mathematics, etc., to the more practical problems encountered in engineering and other professions. The psychologist may spend years in investigating mental processes and discovering the reactions that normally take place in response to certain stimuli, without ever making use of the results obtained to determine the sanity or insanity of a person, to follow the workings of the criminal mind, or to locate an area of the brain that is suffering from some pathological condition. This is pure science. But when the psychologist himself, or the expert in the treatment of mental diseases, or the criminologist, takes advantage of the results obtained by the researches of the psychologist to solve some such practical problem as those indicated, we have to deal with applied science. The neurologist may spend a lifetime in studying the paths of certain nerves in the body of the fish, he being a teacher and investigator in pure science alone. The physician who profits by the discoveries of the neurologist to treat successfully certain nervous affections which before baffled every effort of the medical profession, is studying and practising applied science. The palæontologist studies, classifies and describes the various forms of fossil shells, and is properly regarded as an investigator in pure science. But when he or any other employs the knowledge thus acquired to locate beds of ore, rock valuable for economic purposes, or artesian water bearing horizons, a practical application of pure scientific knowledge has been made, and the work belongs in the realm of applied science.

The teacher of applied science occupies a unique position. He stands between the realm of pure philosophy and pure commercialism, and must have a good measure of familiarity with both. He must be in close touch with every advance in his special branch of pure science, and with modern methods of investigation. To do this successfully, he must himself be an original investigator, actively engaged in promoting the advance of knowledge in his particular field. Only thus can he hope to come into that vital touch with other workers along the same line that will enable him to fully appreciate all that they are attempt-

ing and accomplishing, and to judge intelligently the results of their labors. He cannot, however, shut himself up in the realm of pure science, for he must keep in close contact with those departments of the commercial world which find his branch of science of special value in the solution of practical problems. It is essential that he appreciate the needs of commercial enterprises, for only thus can he know where and how to apply his scientific knowledge for the accomplishment of the most good. He must know the problems of the commercial world, the possible solutions discovered by the scientific world, and be able to apply the latter to the former.

In referring to the broader aspects of this problem, "applied science" has been defined as the application of scientific methods and principles to the study of practical problems. If this definition be essentially correct, then "applied geology" is the application of geological methods and principles to the study of such problems. These problems are encountered for the most part by those engaged in engineering work, more especially the mining engineers, civil and sanitary engineers, topographers, and others whose duties involve a study of the earth's surface or extensive operations carried on below that surface.

In a recent number of this journal,[1] Mr. F. L. Ransome, in a most interesting article on "The Present Standing of Applied Geology," makes "applied geology" a synonym for "economic geology," and suggests very narrow limits for the term, in the following words: " . . . as a synonym of *economic geology,* or what the Germans call *praktische Geologie,* the term *applied geology* is so obviously convenient to express the application of general geological methods and principles to the study of valuable mineral deposits as to warrant its use with this special meaning."

It would seem, however, that if applied science means more than the application of scientific principles to the study of valuable mineral deposits, then applied geology should include much more than the application of geological principles to the study of such deposits. So long as geological principles are applied,

[1] ECONOMIC GEOLOGY, Vol. I., No. 1, pp. 1–10.

we have to do with applied geology, whether that application be made to the excavation of a tunnel for a railway, the development of a body of iron ore, or the location of artesian water supplies.

One very important branch of the United States Geological Survey is engaged in applying geological methods and principles to the development of artesian and other supplies of water. Large railroad corporations retain the services of geologists for other purposes than the investigation of the mineral resources along their lines. Engineering companies engaged in the construction of subways for trolley lines, canals, dams, reservoirs, etc., have their consulting geologists. The dredging of ship channels in rivers and harbors and the keeping of those channels open, the construction of levees to prevent the flooding of great rivers, the building of jetties to direct and control the flow of rivers, all demand some knowledge of geological forces and the laws according to which they operate. Our engineering schools recognize these facts, and provide instruction in the application of geological methods and principles to engineering problems other than those which involve the study of mineral deposits. In some cases this instruction is given in connection with courses in general or structural geology, in others special courses in applied geology are offered. At the Massachusetts Institute of Technology there has been given to civil engineering students, for some years, a course entitled " Applied Geology." The bearing of geology upon the success of civil engineering operations is emphasized but with little or no reference to mineral deposits.

It is true, however, that the application of geological principles and methods to the study and development of mineral deposits constitutes one of the most important departments of applied geology. Probably the majority would consider it by far the most important of all, and it is not surprising therefore to find text-books entitled " Applied Geology " which actually deal with only this one branch of the subject. For example, we have Burat's " Géologie Appliquée," the more expanded title of which shows it to be simply a " Traité du Gisement et de l'Exploitation des Minéraux Utiles," with a few preliminary chapters on cer-

tain more general geological considerations. On the other hand, we have an American text ("Applied Geology," by S. G. Williams) which regards applied geology as "the applications of geology to the various uses of mankind," and which therefore discusses the relations of geology to railroad and other tunnels, foundations of engineering and architectural structures, dams, reservoirs, canals, springs, wells, drainage for agricultural and other purposes, sanitation, agriculture, etc., while the various economic minerals are treated at considerable length. An English text on "Practical Geology" (D. T. Ansted), a term used by most writers as a synonym of "applied geology," outlines the limits of the subject in the following words: "I understand by the expression 'practical application of science,' an account of the different methods by which the various facts of the science, as discovered by actual observation, and the general laws which have been deduced from a careful study of the true value and analogies of those facts, may be shown to bear upon the pursuits of practical men, assisting them in coming to right and useful conclusions in their ordinary business. I hope to be able to show that the facts of geology already recorded, and the general conclusions arrived at, may be thus made use of in the ordinary affairs of life, and applied immediately to practical purposes." This author considers that "the application of geology to mining must ever be the first, and the most deeply interesting of all branches of practical geology." He then devotes some nine chapters, including nearly two hundred pages, to various phases of mining geology. "But mining, in all its branches," we read, "is only one department of practical geology." So there follow some half a dozen chapters, including nearly a hundred pages, devoted to a discussion of the uses to be made of geology in road and canal making, the construction of harbors, breakwaters, quays and bridges, the location of railways and of building sites, the draining of lands, the driving of wells, and in coming to a proper understanding of the decomposition of building stones, the formation and mixture of soils, the behavior of springs and wells, etc. The German interpretation of "Praktische Geologie" is not always the same, Keilhack's "Lehrbuch

der Praktischen Geologie" dealing rather with the making of maps, the preparation of rocks and minerals for study and the methods of investigating their characters, the study of fossils, etc., than with mining geology.

The exact interpretation of such a general title as "Applied Geology" is not a matter of prime importance, however, and enough has been said to show how different such interpretations may be. It might be said, in partial explanation of the more limited usage of the term, that the time was when mining geology was the only "*praktische Geologie*," and the terms were more truly synonymous than to-day. As a result of the great growth of the science, many practical applications of geology are made to-day that were not dreamed of when the term *praktische Geologie* first came into use. It is also true that a writer often applies the general term to the more specialized work, without any intention of restricting it to that phase of the work alone.

It is believed, then, that the scope of applied geology most properly includes all applications of geology to practical problems. If this be true, then the subject must occupy an important place in every thoroughly equipped technical or engineering school. The students in mining engineering are not prepared to enter on their work until they have acquired a knowledge of the fundamental principles of general geology, and more especially a knowledge of the minerals and rocks with which they will have to deal, the structural features of the earth's crust and their relations to valuable deposits that may be involved in those structures, the geological relations and possible origin of the more important deposits in the country, together with some conception of the present state of our knowledge concerning the origin and classification of mineral deposits in general. They should, if possible, be given some practice in geological mapping, to the end that they may be able to plot the surface geology of a mining region and from that gain some idea regarding the underground structure in which the deposits are involved.

It is not the purpose of a course in mining engineering to fit a student to take up, immediately upon graduation, the duties and responsibilities of a full-fledged mining engineer. Practi-

cal experience in mining regions is a part of the training that must come after the years spent in a technical school. The object of the engineering education is to give the student a broader, and in some respects a more exacting training than he is likely to get in his practical experience in some one locality for years to come; to give him an extensive view over the whole field of his chosen work, such as he would otherwise get only after many years of experience; to open his eyes to the possibility of bringing to the solution of problems he may encounter many factors of which he must otherwise remain largely in ignorance; thus to fit him to meet successfully the emergencies that may arise in his professional duties with an intelligent, accurate, creative mind. Experience has shown that a knowledge of geology has often proven necessary to the proper solution of mining problems. Indeed, every mining proposition is a geological problem, be it simple or complicated. Hence a thorough training in geology is essential, if the engineer is to bring to his aid in solving mining questions, the factor that often affords the greatest help.

A recent editorial in the *Engineering and Mining Journal* calls attention to the great need of keeping careful and intelligent records of the geological features exposed in the course of underground workings, especially as those workings may later be abandoned, and become inaccessible through caving, or for some other reason. As is there pointed out, only the largest mining companies can afford to maintain a special geological department, and many cannot even retain the services of a geologist. Nevertheless the records should be kept as well as is possible, as "the results would be of more or less value according to the competence and fidelity of the observer." A geological training should be such as to enable the engineer to appreciate the great importance of the matter in question, and also enable him to keep such records intelligently, and work out from the evidence thus accumulated many points of value to his employers. That this is not asking too much of the young engineer, is indicated by the important results already achieved by recent graduates in certain cases.

The civil engineer must be prepared to meet many problems involving geological factors, and must therefore be equipped with an adequate geological training. As a foundation a general course in the fundamental principles of geology seems essential. Familiarity with the different rock species, and a knowledge of their relative values as building material, road metal, etc., will save the engineer from many costly errors. The effect of rock characters and rock structures on tunnelling, the need of lining tunnels which penetrate certain rocks which at first appear massive and strong, the danger of caving where shearing planes dip toward the excavation, the possibility of continued slipping of morainal deposits along a railroad cut in such material, the probable changes that may be expected in a river meandering in its floodplain, the possibility of locating water-bearing beds, building stones and cement rock even when they do not appear at the surface, the conditions essential for the accumulation of artesian waters and the methods of forecasting the probable behavior of wells to be drilled,—these and many other subjects afford abundant material which may be brought to the attention of the civil engineering student with profit. The topographer needs systematic training in the relations of geology to the varied topographic features of the earth's surface. He is called upon to represent the earth's surface not by an actual copy, but rather by an abstract of its features. No contour map is made by determining the position of every contour with accuracy; on the contrary, a limited number of points are so determined, while the topographer must sketch in the remaining areas. The scale does not admit of copying all features, and the topographer who is to make a map which will show the significant features with expressiveness, must have an understanding of the subject with which he is working. It is not good policy to have an important work on astronomy reviewed by a person who knows nothing of the science of astronomy. Having no appreciation of the subject with which he is asked to deal, he can hardly hope to present an accurate and properly proportioned abstract. Neither can the topographer achieve the best results so long as he has no knowledge of the land forms which he is required to reproduce in a map abstract.

The sanitary engineer finds that he must have certain kinds of soil for various processes of sewage disposal and water purification. Where the loose sands of glacial deltas, outwash plains, or other deposits of like composition, are available certain of these processes may prove practicable, but where only beds of compact clay or till are found, the cost would be prohibitive. The draining of swamps that prove a menace to public health may sometimes be accomplished by boring through to underlying beds of loose sand or gravel, from which the waters find a ready outlet. The direction in dip of the rock structures may determine the liability of cess-pools to contaminate sources of drinking water at considerable distances. The direction of flow of underground waters may cause or prevent such contamination. Such are a few of the considerations that appeal to the interest of the sanitary engineer.

The many applications of geology to these and other branches of engineering cannot be enumerated here, the points above mentioned merely serving to indicate in a general way the extensive scope of the subject. The methods of presenting these practical considerations to the students must vary with every school and every instructor. It will probably be agreed by most of those engaged in teaching applied geology that the geological training given to the engineering student must be far more fundamental and thorough than would be afforded by a brief course relating the details of certain instances of the application of geology to engineering problems. It is necessary that the student be grounded in the general principles of dynamical and structural geology especially, if he is to appreciate the significance of geological phenomena when he encounters them, and be able to reason intelligently and correctly concerning them. The instructor cannot hope that the members of his class will always have to deal with the same problems which he may present to them in the lecture room. Perhaps they may never meet just the same set of conditions which he describes as occurring in concrete cases. The important thing is to open the eyes of the men to the fact that in the past a knowledge of geology has made possible the solution of many difficult engineering problems, that the lack of

such knowledge has often caused disaster and failure, that in the future this history will certainly repeat itself, and that if they are to meet such emergencies properly they must provide themselves with the necessary equipment.

Nothing appeals so strongly to the practical man as a specific case to illustrate a given proposition. The value of concrete instances in illustrating the application of geology to engineering problems can hardly be over-estimated. The student may forget an abstract geological principle before he has left the lecture room; but he will remember an actual case, illustrating the application of that principle, for years. It seems to me that a most important part of the work in teaching applied geology is the securing of details regarding actual cases in which geology has been used to such advantage by practical men. Many such cases can be found by looking over the literature, but another source of wealth is to be found in the cases which come to the knowledge of geologists and engineers, but which have never found their way into print. One cannot help wishing that these edifying experiences might be made available for the benefit of the younger and less experienced men, by publication of the valuable technical details, stripped of the personal features which might otherwise make the publicity distasteful to some of those concerned. Many are the valuable object lessons that would thus be presented to the younger engineers and geologists.

Shall the courses in applied geology be given as distinct courses after the student has acquired a knowledge of the principles of dynamical and structural geology, or shall the two phases of the work be presented simultaneously? In some cases it has seemed best to present the more theoretical aspects of the subject together with the fundamental principles as established by careful investigation, as separate and systematic courses in dynamical and structural geology, embodying in a later course the application of these principles to practical problems. The alternative is to give the applied geology with the pure geology, by showing the possible application as soon as each principle is fairly established. It seems to me that the latter method has the great advantage of arousing and holding the interest of the engineering student, by

showing him the practical value of the knowledge he is acquiring, and of fixing firmly in his mind the general principle by means of the more readily remembered illustration. For example, if the general discussion of folded strata, including the different types of monoclinal, anticlinal and synclinal folds and their general effects upon the rocks affected, be followed by a consideration of the effects of such folds upon engineering enterprises, the student finds the subject of more vital interest to him than would be the general discussion alone. The mining engineer sees the practical value of the subject when he learns the effects of anticlines on the accumulation of oil and gas, the manner in which synclinal troughs serve to collect deposits of metallic ores, the manner in which saddle reefs and inverted saddles are formed, and the importance of such folding in developing fissures along the crests of anticlines and in the troughs of synclines. The detailed discussion of the various mining regions may come later in a course in economic geology, but some reference to the effects of folding on mining problems seems to prove helpful at this point. The fact that pitching troughs and anticlines may prove deceptive is then pointed out, the nature of their outcrops explained, and the effects on exploration and development work discussed. If this be followed by an account of some special case, as where two engineering students working on their thesis succeeded in demonstrating the presence of a pitching fold where none was suspected before, a discovery which eventually led to the opening up of valuable ore bodies, then the student is more ready to appreciate the value of the subject of folds than he would ever be if only the abstract discussion were presented at that time, leaving the practical application till a later course.

So also in the case of the civil engineer. If he is told that the folding of brittle sandstone in a low syncline is apt to break or fissure the rock so that it becomes like an arch inverted and with the "keystone" hanging downward, he may forget it. But when the case of a Pennsylvania tunnel driven into a hill composed of sandstone in this condition, which resulted in the removal of the support from under the keystone and the consequent caving in of extensive masses of the rock, is brought to his atten-

tion, the feature of folding referred to will not soon escape his memory. He might forget a statement that shales which appear solid and massive when first exposed to the air tend to crack and crumble later on. But he will not forget that a certain tunnel driven in such shales, and not lined because the rock appeared so solid and massive when penetrated, collapsed and caused disaster when the shales dried and crumbled.

The value of the general principle itself must not be overlooked in emphasizing the concrete illustration. The principle has a value independent of any application. But to that class of men who come to seek the practical applications of geology more especially, such illustrations serve a most important end in fixing the principal points in mind, in arousing a healthy interest in the work, and in awakening the student to the possibilities of practical utility offered by an intelligent application of the principles of the science.

ORE-DEPOSITS AND INDUSTRIAL SUPREMACY.

JOHN L. STEWART.

Many and varied as are the problems of the economic geologist, the knowledge that his work has to do with seeking out the mainstays of our civilization is a fact that has not received the recognition it most emphatically deserves. Conscious of the distinct technical economic effect of his work, the important relations of ore deposits to fundamental social conditions has not been understood by the economic geologist. The world seems agreed that the United States is likely to achieve economic supremacy; but to maintain the same, means a social equilibrium that cannot be disturbed, an equilibrium delicate and unstable, with which the economic geologist is much concerned; how much, it is the purpose of this paper to indicate.

No subject has been more influenced by the development theory nor has any subject-material for study been so modified by the result of increased knowledge, of scientific relations of man to nature, than that of history. Curiously enough, if one were to examine the standard historical writings, outside of a few common-places or vague references to geographical influences, one would not gain the impression that the study of civilization had in any sense been influenced by the new points of view that have revolutionized all the organic sciences. The traditional literary point of view in the composition of history has inevitably precluded giving the proper emphasis to those influences surrounding man in community life and those forces that were the outcome of conscious effort of man to modify those influences. In other words, there has been no adequate recognition of the part that geology, physiography and economics have played in giving us what we call human development.

It is taken for granted in Germany and in France that among the primary influences at work are those which depend largely on these two great sources of influence. In England there is a

more modified recognition of that significance, but in the United States there is a most unfortunate disposition to regard the tendency to emphasize the part that these particular sets of conditions play as in a sense "vulgarizing" history, making it less interesting, taking away from it its human element and leaving us nothing but a dreary recital of facts. So absolutely wedded are we to classical traditions that the revolutionary effect of this point of view has practically been ignored in academic circles. Here and there, outside of the universities, studies have been made bearing on historical periods, with attempts at new interpretations, which make clear recognition of the part that geology and physiography have played in the problem. We have had detached studies on the relations of history and geography, but nowhere, outside of professional geological courses, has there been any scientific appreciation of the bearings of this important subject on our views of human society. Indeed, for all practical purposes the study of geography is ignored and outside of our military and, perhaps, some of our engineering courses, no recognition is given the study. History, geography and economics are related branches which mutually explain each other, none of which can be well understood alone; as a result of this coordination there is growing up the feeling that history must take its place along with economics, drawing on the one side from the sciences of biology and geology and on the other side from psychology. In other words, instead of being commercial and literary, history has become educational and scientific. It is scientific because it is economic, a fact which gives us the final criterion of civilization. This conception of history has come to be known as the economic interpretation of history, and no matter what its limitations may be, and they are no doubt many, it offers the most fruitful method of securing from history all that it has to give. Economics is the study of the effects of man's modification of his environment in order to satisfy his wants, while engineering is the art of directing the great sources of power in nature for the use and convenience of man. Comparing these two statements, we find they are closely related, and while it is true, political economy, although concerned primarily with in-

dustry and how it should be made productive, has practically neglected to point out those means. It treats of buying and selling, of supply and demand, of rents, interest and wages, of tariffs, of money and currency, of land values, taxes and what not, but with rare exceptions do you run across a treatise that mentions engineering, the most potent force in the economics of the nineteenth century. During the eighteenth century, Adam Smith, having carefully observed the conditions which prevailed in Europe and especially in Great Britain, wrote a book admirably suited to his environment and applicable to conditions then existing. Then men undertook to erect the principles of that book into a universal law irrespective of environment; then others theorized on these commentators, and their successors upon them, until the most practical of business problems has been lost in a metaphysical fog so thick that men nowadays are apt to lecture on political economy as if it were a dogma without regard to the fact that the principles have absolutely no relation to the conditions under which they are being discussed. Therefore there seems no reason at first blush to object to the attitude that men of science have taken to this subject, but there is in the new development every evidence that the scientific point of view, which substantially means the inductive point of view, will recognize that the study of economics must take into consideration all the forces that are at work in every branch of productive industry. Any scheme of education that coordinates modern economics with physiography and economic geology will undoubtedly raise the appreciation of the value of economic geology, particularly as a scientific study and as a means of liberal development.

As illustrative of the possibilities of such a coordination, we may mention the part the smelting of the metals and the search for ore deposits have played in the development of human society. The day is yet to come when the history of the effects of the development of new mining and metallurgical processes upon human society will be written, but a most superficial glance at the lines of human history shows that the impelling motive as the result of economic pressure has been to control sources of mineral wealth, and those peoples who controlled such sources and

knew how to develop them were able to dominate the political situation; it may have been copper, it may have been gold and silver, or iron ore and coal, but all reflecting the same desire to control what were or may become substantially the conditions of survival. As the result of our economic investigations and their bearings upon human activities, it is well understood that movements of peoples have been determined by the pressure of the population upon the food supply; that migrations have been the outcome of the diminishing area of food supply at home; that wherever the cost of living has increased men have been forced to seek new sources of subsistence. In these efforts to find new food areas have come the inevitable collisions,—in other words, war, which is the last form of economic competition. To be possessed of inferior weapons in this competition has ever meant disaster. When the struggling communities were all on the same plane with respect to their material for weapons, say jade, the struggle was evenly balanced unless other factors entered into the problem; but when with the discovery of the uses of copper better weapons could be made than those from jade, then would come a disturbance of the equilibrium and the winning of a decisive advantage by those possessing the improved weapons. The result has been the effort to secure the sources of the metal of the improved weapons either by trade or war, with the inevitable determination to control the conditions of production of that metal. The whole early history of the Mediterranean basin is the history of the struggle of competing economic areas for the control of the sources of material well-being. The Trojan war was undoubtedly a great struggle to control the trade of the Black Sea region; the numerous wars that were waged between the region of the Nile Valley and the Valley of the Tigris and Euphrates were to control the great sources of copper in the Sinaitic peninsula; the mines of Attica played their part in developing the industrial and political policy of Athens; the wars between Rome and Carthage were for the control of the mines of Spain. Rome fell heir to immense sources of wealth, but she was unqualified, in the instincts of her people and by the characteristics of her administrative system, to take up the work of

maintaining the world's stock of metals which devolved upon her by the conquest of nearly all the great fields of production. Unskilled in mining, she resorted to a method of mine administration which had a disastrous effect both upon the mines as properties and their laboring populations. One cause or another in swift succession reduced the labor supply of the mines of the Empire, and despite the efforts to systematize the administration of the mines and to introduce scientific knowledge and technical skill into the conduct of mining operations, the production of metals received a shock from which it did not recover for a thousand years. The result of this economic decline was the long period of stagnation in Western Europe which has passed into history as the Middle Ages.

As to the effects of Columbus' discoveries in the West, those that followed in his steps came upon sources of mineral wealth which for centuries seemed to be inexhaustible. The reaction of this discovery of new sources of metals upon the history of Europe was to make Spain the mightiest state since imperial Rome and paved the way for fierce national rivalries among western European nations that have gone on steadily increasing to our own day. France, Holland and England threw themselves into the struggle with a vehemence that brought about the greatest changes in the relation of European states. England, missing the chance of controlling the great sources of supplies of precious metals, was to discover within her own boundaries a source of mineral wealth that, with the development of new methods of using power, was to make her the dominant industrial state. It is a common-place that England's early exploitation of her coal and iron deposits, combined with her insular position, gave her a predominance in European trade which remained unchallenged until towards the end of the nineteenth century.

What copper was to the ancients, iron ore and coal are to the moderns. The country that can produce the cheapest steel is the country that is going to control the industrial situation, and controlling the industrial situation, all other things are given unto it. The rise of Germany as a competitor of Great Britain is of course

to be traced largely to her skilful utilization of her low grade iron ore. England has been passed by the United States in the race of steel production; our extensive coal and iron deposits have given us a position which inevitably must affect the relations of the modern European states to America.

Momentous as have been the international revolutions in the iron industry, equally significant have been the internal revolutions in the industry in this country which are part and parcel of the general change and illustrate the whole. The first element in the change was in the discovery of new sources of fuel; from 1840 to 1860, eastern Pennsylvania was the main producing district; the fuel was anthracite, the ore was the local ore of Pennsylvania and Philadelphia was the center of the American iron trade. In 1872, when the first systematic statistics of the trade began to be collected, it was found that out of 2,500,000 tons of iron, one-half was smelted with anthracite, one-third with bituminous coal or coke, and the rest with charcoal; by 1875 the output of bituminous or coke iron exceeded that of anthracite and ever since has held the advance; then began the shrinkage in the use of anthracite, which continued until its elimination was complete.

Since 1880, western Pennsylvania has been the center of the American production; in 1890, 40 per cent. of the United States iron output came from the Pittsburg region; the local effect in eastern Pennsylvania on invested capital, as the result of these new deposits, was most disastrous; the increasing competition between the eastern and western parts of the state led to the gradual decline in the number of furnaces, the ability to produce steel was diminished and the great source of revenue in railroad freights was curtailed.

Serious as was the effect of new sources of cheaper fuel, it was exceeded by the capacity to make use of the improved metallurgical processes, which were more easily used through the discovery of new and better sources of ore supply. In the decade between 1860 and 1870, when the Bessemer process came to open vistas for new plants and new methods of administration, it prepared the way for new and wider uses for cheap steel. It was

inevitable, in the development of this process, that the ore deposits of eastern Pennsylvania, which had been the mainstay of the industry there, would become comparatively useless; between 1873 and 1895 the Lake Superior region sprang into a commanding place; although the ore and coal mines are separated by 1,000 miles of land and water, the development of cheap transportation in the last thirty years, which has been the indispensable condition of the smelting of one by the other, has made the revolution complete.

This perfecting of transportation, making possible the transfer of the center of the industry from the Atlantic coast to the Mississippi valley, has been the most remarkable of the mechanical triumphs of the United States.

The shocks to the industrial system of eastern Pennsylvania, which have been revealed in the bitter labor disturbances characteristic of the hard coal regions, were the direct outcome of new sources of ore supply and what follows gives the key to the situation. It was in 1870 that the men interested in the development of the great industries of eastern Pennsylvania, conscious of what seemed to be an impregnable position, aimed to make it so by controlling the then only great source of fuel and during the next ten years took place that great struggle to monopolize the anthracite coal supply. The railroads bought up extensive properties in their race with each other, mortgaging themselves against the future, confident of abundant and increasing returns. But they were not to reap their harvest, for the development of the bituminous coal fields cut away the basis of their industry, causing its collapse.

All the labor troubles and investment problems connected with the industry have, as their basis, this dislocation; the severe crisis has passed, the " integration " of the hard coal industry has been practically accomplished, but the character of the market in 1905 differs radically from that of 1875.

The rise of new industries, notably cement, has given to the railroads the revenue which was lost in pig iron; to-day the Lehigh Valley and New Jersey Central railroads carry more freight in value in cement than ever they carried in pig iron, a

most conspicuous instance of the dependence of industrial activity upon economic geological conditions.

It is a common-place to comment on all the political consequences of this shifting of the greatest of modern industries; where a half a century ago the region east of the Appalachians and north of the Potomac controlled our national policy, to-day it is that group of communities in the upper Mississippi valley whose purposes control the policy of the Union.

The serious problem from the economic side is expressed by the fear of an early exhaustion of our stores of iron ore. Here we have the frank recognition of our dependence upon the economic geologist. What other stores of metals may be found and how they will affect the situation are questions of the future, but when we look abroad we see in the struggle between Russia and Japan an effort to control, what upon good geological authority, are said to be the richest coal and iron deposits in existence. The possession of those great stores by people familiar with modern metallurgical processes and abundant labor and a sufficient transportation system carrying with it proper economic aptitudes, will cause a collision of economic systems such as has been paralleled only in the great struggles between Great Britain and France in the eighteenth century and in the earlier struggles for the control of the Mediterranean basin.

It will be the part of wisdom, in order that those who are to control our industrial and political policy of the future may understand the problem, to make such a coordination in our scientific work of those studies which elucidate each other. To realize the historical consequences of the smelting of the metals, to make mineralogy and geography elucidate history, will give to our efforts a substance of organization that cannot but prove fruitful.

THE TERLINGUA QUICKSILVER DEPOSITS.

H. W. TURNER.

The Terlingua mining district is situated in Brewster County, Texas, in sight of the Rio Grande and about 80 miles in an air line southeast of Marfa, a station on the Southern Pacific railroad. The district and its deposits of mercury minerals have already been described in a number of publications noted under Bibliography at the end of this article. The most complete of these publications is Bulletin No. 4 of the Texas State Mineral Survey, Dr. W. B. Phillips, director.[1] This paper may be considered as supplemental to that bulletin.

The known deposits of quicksilver ores of commercial value are embraced in the east to west zone 15 miles in length, with a width of about two miles. Cinnabar has also been found in Christmas Mountain, northeast of Big Bend and south of the Chisos Mountains, near the Rio Grande. At the latter locality some very good ore has been found. According to the geological map of the region published by the State Survey, both of these deposits are in Lower Cretaceous limestone. It also occurs in Mexico to the west of Terlingua in a lode associated with galena. This lode has not yet been exploited.

THE GENERAL GEOLOGY OF THE DISTRICT.

The formations represented in the quicksilver zone comprise:

1. Tertiary lavas.
2. Upper Cretaceous sandstones and shales.
3. Lower Cretaceous sediments, chiefly limestone, comprising in descending order—Vola limestone about 50 feet thick, Del Rio shale about 100 feet thick, Fort Worth limestone about 100 feet thick, Edwards limestone perhaps 1,000 feet thick.[2]

[1] A paper also appeared in this journal, Vol. I., No. 2, pp. 155–162, by W. B. Phillips.

[2] The magnificent fault scarp at the mouth of the Grand Canyon of the Rio Grande, where it is joined by Terlingua Creek, exposes 1500 feet of

The relation of these formations to one another and the outcrops of the various lodes are shown on the sketch map, Fig. 16.

DEPOSITS IN TERTIARY LAVAS.

The Big Bend District.—To the east of Terlingua Creek and forming the eastern portion of the zone here described, are a series of volcanic hills rising from a basement of Upper Cretaceous shales and sandstones. The topography is in marked contrast with that of the middle and western portion of the quick-

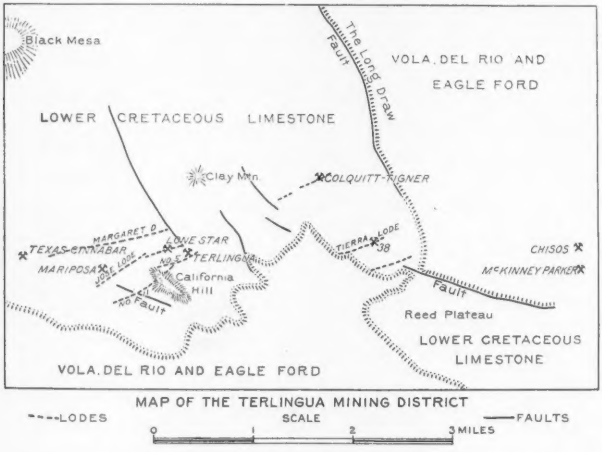


FIG. 16.

silver belt, where limestone mesas predominate. This eastern section is known locally as the Big Bend district, from the post-office of that name. The mines here were only superficially examined.

While cinnabar deposits are found in the sedimentary rocks of this area, they occur chiefly in the volcanic rocks. Study Butte is a flat-topped hill rising 235 feet above the surrounding flat-

nearly horizontal massive limestone, the greater portion of which is presumably the Edwards limestone, but at the mines the thickness of this formation is not yet known. The determination of the above formations is by Robert T. Hill and the Texas Mineral Survey.

lying Cretaceous sediments and having an altitude above sea level of 2,835 feet. The butte is capped by a sheet of rather coarse-grained, light-gray lava, shown by the microscope to be a trachyte, overlying Upper Cretaceous shales, this relation being finely seen on the steep south slope. On the north slope of the butte this lava sheet is flexed downward, dipping under the detritus of the valley. On this north slope the still nearly horizontal shales are seen to *overlie* the lava, showing that the sheet is intrusive and that it here cuts across the bedding planes of the shales. The cinnabar deposits occur chiefly in this lava on the north and east slopes of the butte and at its northeast base. They are being exploited by two companies, the Big Bend Cinnabar Mining Co. and T. P. Barry and associates, the two properties being adjacent to one another.

The ore, so far as known, is entirely in the form of cinnabar, but contains likewise a large amount of iron di-sulphide, presumably pyrite. The lava is much intersected by joint planes and to some extent by seams along which movement has taken place. These joint planes and seams are to a greater or less extent filled with cinnabar, accompanied by some calcite. No quartz or other form of silica was noted. The cinnabar likewise impregnates the whole mass to a slight extent. In the Dallas shaft, at the northeast base of the hill, what appears to be a fissure vein was encountered containing some very good ore, and I understand that the same vein extends westerly into the Big Bend property. On the latter property, on the north slope of the butte, the Upper Cretaceous shales overlying the lava sheet contain at least one rather persistent seam of high grade ore and the values are said to extend into the shale for a foot or more on either side of this seam.

The lava capping on the top of Study Butte has a thickness of less than 100 feet (not measured), but the Big Bend shaft is 220 feet deep all in the lava. It is about at this point, however, that the lava sheet dips down and the vertical shaft is not, therefore, penetrating the sheet perpendicular to its upper and under surfaces. Should the shaft be extended through the lava, it is quite possible that bodies or flat-lying lenses of pay ore will be found in the sedimentary rock beneath.

The same would apply to the Dallas shaft, which is, in its lower part at least, in the lava.

In both shafts considerable water was encountered, the larger part of which is removed by pumps in the lower-lying Dallas shaft. This strong flow of water has been a source of difficulty in sinking.

I am indebted to Mr. W. L. Study, former superintendent of the Big Bend mine, for the following analysis of the mine water. This analysis was made by the Dearborn Drug and Chemical Co. of Chicago, W. A. Converse, analyst.

ANALYSIS OF BIG BEND MINE WATER.

	Grains in One Gallon.
Silica	2.663
Oxides of Al and Fe	trace
Carbonate of lime	trace
Sulphate of lime	60.832
Carbonate of magnesia	21.019
Sulphate of magnesia	28.600
Sulphates of sodium and potassium	138.921
Chlorides of sodium and potassium	4.950
Loss, etc.	0.325
Total	257.310

The water was highly impregnated with sulphuretted hydrogen.

In a lava hill known as Maverick Mountain, east of Study Butte, T. P. Barry and associates are also opening a vein said to carry cinnabar ore of good grade.

DEPOSITS IN SEDIMENTARY ROCKS.

In the shales and sandstones of the Upper Cretaceous (presumably the Eagle Ford formation), in Section 248, Block G 4, is a very interesting cinnabar deposit belonging to the Colquitt-Tigner Mining Company. It has been opened up by vertical shafts with drifts below and by open cuts and adits. The shales and sandstones dip at gentle angles and are cut by fractures along which the cinnabar has been deposited. The two strongest fissures noted strike one N. 70° to 75° E. and the other a little to the south N. 63° to 65° E., both being nearly vertical

or dipping south at steep angles. The curious feature of this mine is a vertical pipe of oval or circular shape composed of broken up material, the horizontal diameter of the pipe being perhaps 75 feet. At the surface this pipe shows as fine gray comminuted material resembling volcanic ash, but I am informed by Dr. Phillips that a microscopic examination shows no evidence of volcanic origin. The vertical shafts are sunk, one a little west of the pipe and the other at its east border. The pipe is also penetrated by drifts from these shafts and one drift curves one-third way around it. In these drifts the pipe below may be seen to be composed of angular fragments of shale and sandstone, cemented by calcite and a bituminous substance. This bitumen runs down the sides of the drifts from cavities in the cemented material and is quite abundant. There are said to be only traces of cinnabar in the pipe itself. No volcanic material was noted in the pipe anywhere or in any of the mine workings, and no explanation of the formation of this pipe in nearly horizontal sedimentary beds occurs to the writer. About one mile to the northwest is a volcanic hill, known as Cigar Mountain. The mine deserves a careful study by a competent geologist.

The Chisos and McKinney-Parker Mines.—Another more important deposit from a commercial standpoint is found in the Eagle Ford formation at about the middle of the quicksilver belt, as previously outlined. It has been opened up by the Chisos Mining Company, operating on Section 295, Block G 4, and at the McKinney-Parker mine on Section 70, Block G 12.

The ore is cinnabar, occurring in a gangue of calcite in true fissure veins. The Eagle Ford sediments lie here also at gentle angles, and the veins cut the bedding planes at steep angles. The dip of the main vein of the Chisos mine as seen in the incline is about 70° S. E., the general strike of the vein being about N. 30° E. Most of the ore extracted is of high grade and is found in seams and in small bodies up to four feet in thickness. The ore has thus far been reduced in retorts. As the shales and sandstones on either side of the veins contain values, there is probably considerable ore of a furnace grade on the properties.

According to B. F. Hill[1] (Bull. 4), the ore also contains a little gold.

DEPOSITS IN THE LOWER CRETACEOUS.

The Lower Cretaceous rocks, as before noted, include the Vola limestone, the Del Rio shale, the Fort Worth limestone and the Edwards limestone. The first two formations are not known to contain cinnabar in commercial quantities except certain portions of the Del Rio shale, as hereafter described. These formations are therefore placed with the Eagle Ford on the map (Fig. 17), the whole constituting a non-productive series except in the area east of the Long Draw.

The Lower Cretaceous series form the mesas of the western part of the quicksilver belt or what may be designated the Terlingua district proper. From the larger part of these mesas the Vola limestone and the Del Rio shale have been eroded, so that the next underlying member, the Fort Worth limestone, forms the surface in most places. The lodes in this formation have thus far been the main source of the quicksilver of the district. However, since no sharp line can be drawn between the Fort Worth and Edwards limestones, and since the lodes extend down into the latter, they will, for the purposes of this paper, be considered as one and designated the Lower Cretaceous limestones.

The Terlingua district proper is located on the main Lower Cretaceous limestone mesa, extending from the Long Draw west to Las Tres Cuevas Hill. This mesa is cut by numerous arroyos, often formed along lines of faulting. The average altitude of the top of mesas above sea-level is about 3,300 feet. The district is bare of trees and the only available water is rain water impounded in masonry tanks or caught from the roofs of houses.

An observer, standing in a commanding position in the productive area, and looking south, will perceive a series of white-capped hills, and will also note a few similar isolated hills within the productive area, notably California Hill and Clay Mountain. These white-capped hills represent the uneroded portion of the Vola limestone and the Del Rio shale, the limestone forming the white caps, and the soft shales the slopes visible from the standpoint of the observer.

[1] Bull. 4, University of Texas Mineral Survey.

The Vola limestone contains small irregular veinlets of calcite, which presumably carry traces of cinnabar, but such seams usually break up and disappear in the underlying shale.

The Del Rio shale is, however, cut by numerous seams of a white, transversely fibrous mineral, not attacked by HCl and probably gypsum. Usually a little iron oxide, or sometimes pyrite, may be noted along the borders of these seams, and if samples are crushed and washed, cinnabar is almost always found to be present. While filling joints and fractures in all positions, the gypsum seams more often lie nearly horizontal; that is, roughly parallel to the bedding planes of the shale. The dark unaltered shale contains considerable iron di-sulphide, chiefly, if not entirely, pyrite. This is disseminated through the rock and also deposited in little veinlets and in nodules. Where these nodules are oxidized they are frequently hollow, sometimes showing a little cinnabar in the center, which may originally have been disseminated through the pyrite and subsequently concentrated during the process of oxidation. The shales immediately above the quicksilver lodes are often broken and crushed, and then usually contain cinnabar as paint on the surface of the fragments. The shales in this case are reddish and oxidized. In one instance, a horizontal layer of shale was noted, red and oxidized in one part and dark in color and unoxidized in another.

The massive Lower Cretaceous limestones contain all the profitable lodes of the mesa. On the map (Fig. 1) several of the stronger lodes are shown, but there are many others. While not parallel, their strike is in a general northeast to southwest direction, the dip being approximately vertical. The lodes are distinctly of the nature of fissure veins and are mineralized lines of faulting, along which the thrusts have been largely horizontal This is clearly shown by the prevalent horizontal groovings on the walls of the lodes. There have been, however, small vertical throws, resulting at some points in the dropping down of masses of the Del Rio shale between lime walls below. This is finely seen on the Margaret D. lode and in shaft No. 1 on the property of the Marfa and Mariposa Co. The latter shaft is 50 feet deep, the lower part being in a crushed body of dark shale, and the

collar on a level with the top of the surrounding lime country rock. This shale is sharply separated by movement walls from the adjoining lime and is apparently in every way similar to the Del Rio shale in general, except in being much crushed. Cross-cuts show this shale body below to have a width of about twelve feet. As a rule, where the shale has been faulted down, it is reddish and oxidized, often containing enough cinnabar to form a low grade ore.

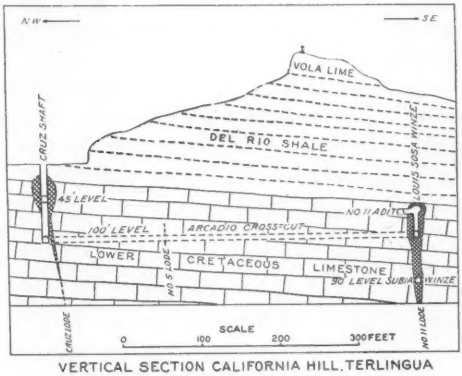
It would then appear that the massive Lower Cretaceous limestones were divided by vertical northeast to southwest fractures into a nearly parallel series of blocks and wedges, and that horizontal movements took place, grinding up the limestone along these fractures and forming in some places masses of friction-breccia and in other places open spaces. The fracturing and horizontal thrusts were presumably the result of the same stresses and perhaps concomitant. These stresses evidently exerted a much slighter effect on the overlying Del Rio shale, as may be well seen in the uneroded bodies of this shale in California Hill, the fractures practically dying out in the lower part of the shale body.

The Lower Cretaceous lodes may be divided into two kinds, according to the composition of the vein matter:

1. Friction-breccia lodes.
2. Calcite lodes.

In the friction-breccia lodes the vein-matter is clearly made up of triturated and crushed limestone and shale, cemented by calcite and gypsum, and originally containing much iron di-sulphide, which in nearly all cases has since been oxidized. In the unoxidized crushed lime of some parts of the 300-foot level, main shaft, of the Marfa and Mariposa Co., pyrite and cinnabar are both present. These friction-breccia lodes are by far the most important commercially, as may readily be seen by examining the mine dumps. Two of the most important of these lodes, No. 11 and No. 5, are shown on the map. The broken up vein matter formed a ready avenue for the ascent of solutions and gases containing the values, as well as a convenient place for deposition. These lodes tighten up in depth in the great majority of cases and are not then profitable.

Fig. 17 shows a vertical northwest to southeast section of California Hill through the Cruz shaft and the Louis Sosa winze. This section cuts the Cruz lode and No. 11 lode. It will be observed that these lodes are shown as ending upwards at the Del Rio shale. This material, being more or less impervious to the solutions, appears to have acted as a barrier and to have caused the deposition of the cinnabar directly under it, and it is in exactly this position that all of the large and rich ore bodies have



VERTICAL SECTION CALIFORNIA HILL, TERLINGUA

FIG. 17.

thus far been found. In some cases exploitation in depth directly below these rich bodies has proven the existence of ore of a good but lower grade to the depth of about 100 feet, with the ore still going down; in other cases, the vein pinches and the ore gives out.

Of all the lodes exploited, No. 11 is apparently the most promising. This in part follows along a dike of intrusive rock to be hereafter described. The fracture followed by this lode shows the greatest amount of crushing and movement, and this fact, taken in connection with the proximity of the dike, suggests that it may continue and be profitable to a considerable depth. A bore hole sunk with a churn drill to the depth of 446 feet on this fissure shows lode material in the bottom.

As is well known, movements resulting in the formation of

fissures have usually taken place in a vertical or highly inclined direction and such fissures when strong and of a considerable horizontal extent, may reasonably be expected to continue to a great depth. But with fissures formed by horizontal thrusts, the case is not so clear, and it would appear that they are much less likely to be continued to great depths. It is certainly the case that many of the smaller lodes of the Lower Cretaceous limestones at Terlingua do pinch out in depth. This interesting question will doubtless be settled by the vigorous exploration now going on on the property of the Marfa and Mariposa Co., whose deepest shaft is now down 300 feet. A drift from this shaft has encountered an oxidized lode carrying cinnabar and precisely similar to some of the surface lodes.

The fact of a lode pinching below is not always an indication that it has given out, for some of the stronger lodes repeatedly pinch and open out again both vertically and horizontally. A case of local horizontal pinching is seen with No. 5 lode where it is cut by the Arcadio drift (see section of California Hill, Fig. 18). At the point marked No. 5 on the vertical section, there is no indication of a vertical seam, yet to the east in the bottom of the Tercero shaft, the lode is still strong and the bottom of this shaft is 60 feet or more vertically below the Arcadio drift. No. 5 lode is also strong west of the Arcadio drift.

Calcite Lodes.—In many of the lodes the chief vein matter is calcite. The strongest one of this character in the district is the Margaret D. on Sections 41 and 40. This lode has a strike about N. 75° E. and a nearly vertical dip, the width varying from 2 to 10 feet. It is over a mile in length. The calcite in this typical fissure vein is largely deposited in layers parallel to the walls, forming a striking example of banded structure. At many points ground-up material and irregular masses of shale faulted down (in one case 30 feet) may be noted. Considerable ore of a one per cent. or lower grade has been extracted from this lode, the better ore being associated with the shale and ground-up material. A large amount of the white calcite contains cinnabar which forms a very pretty ore, the bright red cinnabar contrasting strongly in color with the white calcite. Such ore is

deceptive in appearance and usually contains less mercury than one would suppose, much of it averaging only one-fourth per cent. mercury. On account of the poor breaking qualities of the calcite, such ore is not at present profitable. In addition to cinnabar, the Margaret D. lode contains small amounts of an oxychloride of mercury, known as Terlinguaite, and of a volatile hydrocarbon.

Taken as a whole, the lodes composed largely of calcite have not thus far proved very profitable, although occasionally good are bodies of limited dimensions have been encountered, as on the Excelsior lode at the Colquitt-Tigner mine, and on the José lode on the Marfa and Mariposa property.

Tierra Lode.—On section 38 is a strong lode over 2,500 feet in length, composed in part of red shaly material (locally known as *jaboncillo*) and in part of calcite, along which movements have taken place apparently in part subsequent to the time of its formation, resulting in a series of cracks, some lying nearly parallel to the lode (that is, dipping southeast about 80°), and some nearly vertical. Surface waters percolating downward along these fractures have dissolved out more or less of the calcite of the lode and to some extent the adjoining limestone, forming open fissures and caves. The main open fissure was formed along the middle line of the vein, so that it is bordered on either side by more or less vein matter. This main open fissure has been followed horizontally by drifts from the Lafarelle shaft for a distance of 460 feet. The fissure varies in width from a fraction of an inch to several feet, and has to a greater or less extent been filled with loose material washed down from above, and its vertical extent exceeds 150 feet, for it continues down below the 150-foot level of the Lafarelle shaft. On the 100-level and 150-level bones and teeth of extinct mammals were found imbedded in the detritus. These bones and teeth were examined by Prof. J. C. Merriam, of the University of California, who states that some of them are the remains of an extinct ground sloth, and that some of the teeth are horse teeth of an extinct species. The age indicated by the remains is probably Pliocene.

A little to the east of the Lafarelle shaft this lode originally

contained a body of good cinnabar ore in a soft matrix. This material, gradually disintegrating, enriched the detritus to such an extent as to form ore containing from one-half per cent. to 4 per cent. mercury. Numerous boulders of nearly pure cinnabar were found in it. Remnants of the original ore body in the vein proper are found alongside of this tierra ore. About 500 tons of this ore have been extracted, and it continues down below the 150-foot level, although there of lower grade.

Period of Vertical Faulting.—After the period of horizontal faulting and probably subsequent to the main period of ore deposition, the Lower Cretaceous limestones and overlying sediments were cut by a series of northwest to southeast fractures, along which vertical or highly inclined thrusts have taken place. On the map several of the stronger of these faults are shown. In case of the fault shown as southwest of California Hill, groovings are still plainly to be seen on the escarpment, these groovings being inclined to the southeast about 45°. On many of the fault-walls patches of the friction-breccia still adhere. No finer examples of the direct influence of faulting on topography can be seen than in the Terlingua district, where many of the cliffs are due directly to faulting, portions of the original fault fractures being so well preserved as to convince the most skeptical.

Joints.—The Lower Cretaceous limestones are intersected by abundant vertical joints with a northwest to southeast strike or at right angles to the trend of the lodes. These joints are often strongly developed (see Fig. 18). Frequently calcite is deposited along them and at some points, where movement has taken place small ore bodies have formed. These joints do not appear to have exerted any influence on ore deposition where they intersect the lodes, as they seem to be as well developed where no ore is found as where the values occur. At a few points, however, cinnabar may be noted in these joints or crossings, where they intersect a barren part of a lode.

Igneous Rocks.—In the Terlingua district proper, lava or porphyry has been found at but two points, namely California Hill and Black Peak, close to the Clay Mountain. The Texas Survey likewise describe a rhyolite as occurring in the interior

portion of the Black Mesa as a laccolith, but this is outside of the zone where deposits of commercial value have been found. The lava of Black Peak is basic in character and shows porphy-

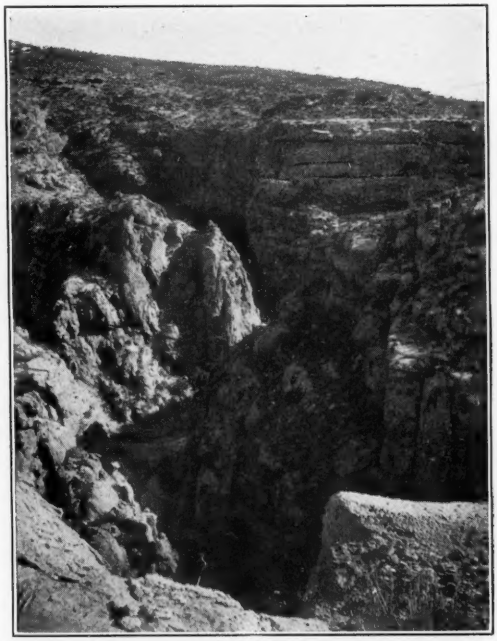


FIG. 18. View in Croesus Canyon near the Mariposa furnace showing horizontal bedding and vertical jointing in the lower Cretaceous limestone.

ritic greenish crystals, said by B. F. Hill to be olivine. Hill calls the rock a basalt. The lava or porphyry of California Hill when examined under the microscope is seen to be an andesite. Macroscopically, the rock is, when fresh, hard and fine grained, of a greenish color and showing numerous phenocrysts of hornblende.

Origin of the Ore Deposits.—The richest ore bodies of any size have thus far been found under California Hill or within 1,000 feet of it, although good bodies up to $15,000 or more in

value have been extracted from section 38, two miles distant in an air line.

California Hill is penetrated by at least two dikes of andesite, which in places have spread out between the strata as intrusive sheets. One of these sheets now forms the top of the middle portion of the hill, the rocks formerly overlying it having been eroded. The southwest portion of No. 11 lode follows one of these dikes, which is here much oxidized and contains cinnabar. At one point a pocket of solid cinnabar, perhaps five feet in diameter, was found at the contact of the dike and the adjoining limestone. As a rule, however, exploration of the dike has not shown up ore of value.

The source of the cinnabar is a matter of conjecture, but there is little doubt that it was deposited in its present position by ascending hot water, containing it in solution and probably also by sublimation from gases. The occurrence of the best ore bodies in the vicinity of the intrusive rock suggests that it may have furnished the heat, and was thus the primary cause of the formation of the heated solutions and gases which transported the mercury from below up through the fault-fractures and deposited the same therein. Very likely a careful chemical examination of the fresh andesite would show no traces of mercury, that rock having been rather an agent in the transportation of the ore than a source of it.

Production.—The following companies have been or are operating on lodes in the Lower Cretaceous limestones: The Marfa and Mariposa Mining Co., The Terlingua Mining Co., The Colquitt-Tigner Mining Co., The Texas Cinnabar Mining Co., The Lone Star Mining Co.

Of these only the first three have reached the productive stage. The total product of the mines up to December 31, 1905, is not far from 25,000 flasks, the Marfa and Mariposa leading with about 20,000 flasks to its credit.

MINERALS OF THE QUICKSILVER LODES.

Calcite.—Calcite is by far the most prevalent vein mineral throughout the entire zone of quicksilver deposits. It occurs as

an original deposit and as a lining to caves in the lodes, these caves being of later origin than the lodes. It is crystallized in a variety of forms. Some groups of dog-tooth spar crystals in cavities contain cinnabar in their interior, and if these cavities, as is likely, were formed after the lodes, it would appear that some of the cinnabar was deposited at a time subsequent to the main deposits.

Gypsum.—Sulphate of lime or gypsum is very abundant in the friction-breccia lodes, and is regarded as a secondary mineral formed during the period of oxidation, the sulphur being set free in the oxidation of the pyrite. In one cave, lined with curled stalagmite-like growths and crystals of gypsum, the gypsum appears to be forming at the present time. In the bottom of this picturesque cave there is clear water nearly saturated with mineral matter, giving it a bitter taste. The temperature of the cave is high.

Aragonite.—According to B. F. Hill, aragonite is common in the lodes west of the Terlingua post office.

Chalcedonic Quartz.—Silica in any form has not been noted in the profitable lodes in limestone, but occurs as a coating on lava fragments along a calcite vein that cuts across the lava cap of California Hill. It is also found in some lodes near the Black Mesa and at other points.

Iron Disulphide.—As already noted, iron disulphide (in part at least pyrite) is common in the Del Rio shale and in unoxidized lode material from below. It was undoubtedly present in all of the friction-breccia lodes, but has undergone oxidation. In the cinnabar deposit of Study Butte it is very abundant in the lava.

Hematite and Limonite.—In the oxidized lodes, hematite and limonite are abundant.

Black Oxide of Manganese.—As a coloring to calcite, black oxide of manganese is occasionally found.

Hydrocarbons.—The nearly universal presence of hydrocarbons in quicksilver lodes has never been satisfactorily explained. It is rare in the lodes of the Terlingua Lower Cretaceous limestones, but is found in the calcite of the Margaret D. lode and in the black shale of shaft No. 1, on the property of the Marfa and

Mariposa Mining Co. Its abundance in the peculiar pipe of the Tigner mine on section 248 has already been noted.

Cinnabar.—All of the mines contain cinnabar as the most abundant mercury mineral. It is usually in a granular form, but locally occurs in well-formed crystals.

Oxychlorides.—In the lodes of the Lower Cretaceous, particularly in the Tercero shaft of No. 5 lode, oxychlorides of mercury, in association with native mercury, are abundant. Many tons of ore have been reduced in which they form the values. These oxychlorides are new species and have been described by Prof. Alfred J. Moses, of Columbia University, N. Y. City (see Bibliography).

Terlinguaite is the most abundant oxychloride. It is found not only in the Tercero shaft, but in other places in No. 5 lode, as well as sparingly in the Margaret D. calcite lode and elsewhere. It occurs chiefly in an earthy form, mixed with gypsum and other impurities. One cave in the Tercero shaft workings was nearly filled with white granular gypsum containing streaks of terlinguaite. Occasionally both cinnabar and terlinguaite are found in the same hand specimen, but this is not usual.

Eglestonite occurs chiefly as well-formed crystals lining cavities, which may also contain native mercury, terlinguaite and calomel.

Montroydite is quite rare, but occurs in association with the other oxychlorides.

Calomel.—Chloride of mercury or calomel is found as a white bloom on ore fragments and also as crystals, which are often rectangular in shape with truncated corners. These crystals are colorless and transparent.

Fluorspar.—According to B. F. Hill, fluorspar has been found in the lodes, but has not been observed by the writer.

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DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, South Bethlehem, Penna. The full name of the author should be attached to all communications.

WHAT IS A FISSURE VEIN?

Sir:—Dr. Raymond's definition of a fissure vein is also very exactly my conception of it. "A fissure vein is a mineral mass occupying a fissure in the earth's crust."

A most important step in the inquiry immediately develops—What is a fissure? The Century Dictionary defines it as follows:

"*Fissure:* A narrow longitudinal opening or groove; a cleft, crack or chink; a line of separation in any substance produced by parting or cleavage; as a *fissure* in the earth or in a rock."

The Standard Dictionary as follows:

"*Fissure:* A narrow opening produced by the parting of a substance or appearing as if so produced; a crack or crack-like depression; a cleft, slit or furrow."

According to these definitions, large rifts or chasms in rocks produced by dislocation are fissures; openings produced by fracturing, whether along zones of fracture, or along diversely-trending fracture, are fissures; cracks following joint-planes are fissures; openings of whatever size formed by movement along the stratification of a sedimentary rock or along the schistosity of a metamorphic rock, are fissures; and the openings produced by strain and movement, along like cleavages of crystals, though so small as to be invisible to the naked eye, are fissures. In short, if we exclude original openings in rocks (the pores of sandstone, the gas-cavities of lavas, etc.) and openings caused by the re-

moval of material in solution (such as are present in many rocks, especially limestones), practically all openings are fissures (spaces of rending or *discission,* to use Pošepnỳ's term). Therefore orebodies formed along faults, fracture zones, intersecting or reticulating fractures, shear-zones, joint-planes and cleavage-planes, are fissure veins.

Plainly I have jumped the track along here somewhere, which is what most inquirers have done before me; and they have found a way out of their bewilderment by creating a thirty-third degree of fissure-veinism — the *true* fissure vein, all others being false or not-fissure veins, as the logicians would say. The true fissure vein is the Simon-pure, un-adulterated article, too elusive to be capable of definition, and known especially by its works, in that it extends " as deep as human ingenuity can devise means for hoisting," to quote the promoter's prospectus, which is at present the true home of true fissure veins.

Considering it, however, unnecessary to argue that any fissure vein is a true or genuine fissure vein — else it is not a fissure vein — I will revert to the simpler phase. In a previous publication[1] I tried to dispose of some of the difficulties above indicated by limiting in respect to size the range of the word fissure, as used in mining geology. I defined strain-cracks in rocks, large enough to be distinctly visible to the naked eye, as *fractures;* while fissures were considered to be strain-openings larger than cracks. Thus I succeeded in elminating from the definition of fissure-veins the ores deposited along joints, fractures and cleavages, as well as replacement deposits, where the mineralizing solutions have usually gained access along large and small strain-openings which they have subsequently cemented with minerals. Ores deposited in strain-openings larger than cracks I designated as filled deposits, and, not daring to ignore the ancient and honorable fissure vein entirely, I referred to it as the best type of the filled deposit.[2] But it will be seen that another well-seasoned term " gash-vein " still came under my definition, or at least such

[1] " Geology Applied to Mining," *Engineering and Mining Journal,* 1904.

[2] " Geology Applied to Mining," *Engineering and Mining Journal,* 1904, p. 191.

gash-veins as represent the filling of stain-cavities larger than cracks; and "imbricated veins," "linked-veins," and any number of terms designating particular forms, so long as these veins have originated in the specified manner. For the term "fissure-vein" is a genetic term, however much the connotation of origin may have been exchanged for physical features supposed to be characteristic of this origin. In the last analysis, it allows no definition but Dr. Raymond's — a mineral mass occupying a fissure.

I believe the term fissure-vein originated at a time when a large proportion of known mineral veins were filled deposits, and represented the filling of pre-existing spaces corresponding in size to the resulting vein. The specific value of the term "fissure-vein" over "vein" was then originally not so great as later on. Thus Von Cotta,[1] who in 1850 classified certain ore-deposits as "true, simple fissure-veins," gave the following sub-divisions: transverse veins, bedded veins, crevices and veinlets (often falling into the two first sub-divisions). Indeed, up to the present time the popular conceptions of "veins" and "fissure-veins" have been very nearly identical. Thus the Century Dictionary makes *fissure-vein* synonymous with *true vein;* and the Standard Dictionary defines *vein* as "the filling of a fissure or fault in a rock, particularly if deposited by aqueous solutions."

With the accumulation of knowledge, however, the miner-geologist has frequently recognized the fact that many veins, of the class formerly called fissure-veins, have not originated by the filling of fissures. In these cases it has become necessary to drop the old term, or re-define it; and out of reverence for a tradition numerous reputable writers have chosen the latter alternative. The varied group of ore-deposits which still frequently retain the old name with some writers, though they have long outgrown it with others, is fairly stated by Ries[2] as follows:

"A fissure vein may be defined as a tabular mineral mass occupying or closely associated with a fracture or set of fractures

[1] "Gangstudien," Freiberg, 1850, p. 80.

[2] Economic Geology of the U. S., p. 236. Taken from Lindgren, *Trans. A. I. M. E.*, XXX; 578.

in the inclosing rock, and formed either by filling of the fissures as well as pores in the country rock, or by replacement of the latter (metasomatism). When the vein is simply the result of fissure filling, the ore and gangue minerals are often deposited in successive layers on the walls of the fissure (Rico, Colorado), the width of the fissure and the boundaries of the ore mass being sharp. In most cases, however, the ore-bearing solutions have entered the wall rock and either filled its pores or replaced it to some extent, thus giving the vein an indefinite boundary. Therefore the width of the fissures does not necessarily stand in any direct relation to the width of the vein (Butte, Montana)."

The latter part of this definition, being paraphrased, states that most "fissure-veins" are chiefly impregnation or replacement deposits — and this, in my experience, is true. According to such a conception, the lead-silver deposits of Aspen and Eureka (replacement deposits due chiefly to the alteration of strained and shattered limestone near faults) are fissure veins. This statement is not far-fetched, for the ore-deposits of Tonopah have a similar origin; yet, being in relatively insoluble andesite instead of limestone, the resulting ore-bodies are confined to the chief fracture-zones (instead of extending irregularly away from them, as they do in limestone) and so present the clean, regular and relatively persistent form of deposits which it is still the delight of many to classify as a "true fissure-vein." The Comstock lode has never been otherwise classified, yet it is very likely that its origin was similar to that of Tonopah veins.

Therefore I recognize the existence of fissure-veins, but confine the recognition to veins which have filled pre-existing rifts, larger than cracks; and I do not recognize the popular attributes attached to the name, such as necessary deep-seated origin or necessary persistance in depth. Unquestionably these veins are more characteristic of the deep-seated portion of the crust; and their extension in any direction is a most uncertain thing. And, as popular belief in these attributes is so closely connected with the term, I question whether the most progress would not be made by dropping the term altogether from ordinary use.

J. E. Spurr.

Sir:—A plausible definition of fissure vein would be the following which is derived by putting an arbitrary limitation upon the obvious or, as one may say, the primitive significance of fissure vein; *viz:* A vein of essentially tabular form and of noteworthy extension occupying and lying wholly between the walls of any comparatively simple break through the country, provided the break does not follow some original or essential structure of the rock.

This definition covers many instances of vein occurrence within my own experience and leaves the way open for a separate designation applicable to veins which follow stratification or schistose structure.

A. C. SPENCER.

THE PHASE-RULE AND CONCEPTIONS OF IGNEOUS MAGMAS.

DISCUSSION OF PAPER BY MR. T. T. READ.

Sir:—In a recent paper[1] on the application of the phase rule to igneous magmas, the author has undertaken the very commendable task of directing attention again to a most important relation but his treatment of the subject promises to lead to some unfortunate confusion. The fact that but little good experimental work has yet been done in the application of the principles of physical chemistry to the question of magmatic differentiation, has placed little material at the disposal of petrologists. The existing literature is also largely contained in European publications. For these reasons the author is perhaps unfamiliar with certain experimental facts which render questionable some of the assumptions which he has made.

Unfortunately, the case is not so simple as the author is inclined to believe, and some of the assumptions which he has found necessary are subject to direct experimental verification. The experimental tests of these has shown them to be inaccurate, and it is therefore desirable to correct them. The most important of the assumptions, and the one upon which the author bases substantially all his deductions, is that the components of our ordi-

[1] ECONOMIC GEOLOGY, Vol. I., p. 101.

nary rocks may be considered as four in number; thus SiO_2 and Al_2O_3 are assumed to be separate components, but calcium, magnesium and ferrous oxides, being mutually replaceable, are considered as one component. He also assumes that potassium and sodium oxides may be considered as a single component, and that Fe_2O_3 can replace Al_2O_3 without altering the complexity of the system. If we examine these relations experimentally, we find that neither the oxides of calcium, magnesium, iron nor the alkalies can be grouped as one component. The number of components in ordinary rocks is therefore not four, but six or more. The conclusion that the rocks mentioned in the paper are stable because they have four phases present, must therefore also be regarded as inaccurate. They could be stable with from one to four phases, assuming four components or, if the number of components is increased, a considerably larger number of phases could be present in the rock and still have sufficient variancy to enable it to exist over a range of temperatures and pressures.

Among the phases which the author has considered stable in the rocks, we find glass. It is now very generally agreed that glass is to be regarded as a supercooled liquid and therefore not stable. None of the rocks containing glass can therefore be considered stable, for the existence of a state of equilibrium is the test of stability. In the same way, those rocks which are considered unstable because of the presence of six phases may or may not be in equilibrium.

It appears that the author has partly realized his error in considering glass to be stable, for he states explicitly that its presence is to be regarded as evidence of "incompleted transformations."

The ruling out of H_2O as a component of these systems, while rendering the discussion easier, must be regarded as unfortunate and unwarranted in view of existing information about lavas, and particularly after conceding water to be the most important factor in ore deposition. The relation of water to these systems is the most important subject suggested by the title of this paper, and it will perhaps not be out of place to express the hope that the author will at a future time give some attention to this but little understood field.

In selecting the alloys of copper and tin for illustrating his discussion, an oversight has been made regarding the nature of these alloys. Cu_3Sn exists under certain limited conditions, but metallic copper as such never crystallizes from any mixture of copper and tin. It was also an unfortunate choice of words which led the author to use the expression "solid solution" on page 110. The term solid solution has been appropriated by physical chemists to signify an entirely different thing from a solution which is merely more or less rigid.

In discussing the different nature of the first and last lavas to be ejected from a common source, the author has called in the idea of two liquid layers. This is ingenious, but to date no mixture of silicates forming two liquid layers is known,[1] and while such a mixture may exist (as indicated by some of the borates), it is questionable if one is justified in offering a hypothesis in support of which we have no positive facts. So far as our present experiments have gone, the ordinary rocks when fused are *miscible in all proportions.*

In discussing the viscosity of magmas and the probability of changes in concentration produced by convection currents, it also seems rather early to draw conclusions. Some natural rocks melt to very limpid fluids in which convection currents, especially when aided by steam, could readily produce such effects, while others, like the feldspars, are extremely viscous.

The author's conception of stability, — *i. e.*, that only reversible relations are stable—will hardly be accepted by physical chemists. Neither is it a generalization to say that "most minerals exhibit a tendency to set up as few centers of crystallization as possible." The experience of this laboratory (see also Roozeboom and Tammann) indicates that several factors influence the number of centers of crystallization, and that the number is to some extent characteristic of the individual composition. While we know that several melted minerals require no *inoculation* to bring about crystallization, others can remain in contact with a crystalline phase for a very long period of time without producing any change.

[1] See Vogt, "Die Silikatschmelzlösungen," Vol. I., p. 100; Vol. II., p. 228.

It is worth while for all of us to remember Roozeboom's very apt comment,[1] "Dabei laüft noch viel Unklarheit unter und eine grosse Neigung zu verfrühter Generalisierung."

A. L. Day,
E. S. Shepherd.

Geophysical Laboratory,
Carnegie Institution of Washington.

THE UNIVERSITY TRAINING OF ENGINEERS IN ECONOMIC GEOLOGY.

Sir:—A year or two ago a humorous paper in England published a squib that expresses one of the grievances of the teacher of geology.

A burly, over-prosperous looking business man calls at the office of the president of an institution of learning to make clear just what kind of an education he wants his boy to have. He lays it down to the president that he doesn't wish to have his son waste his time and bother his brains about fossils and faults and crystals and nonsense of that sort. "All I want you to teach him," says he "is how to find gold and silver or other precious minerals in paying quantities, sir — in paying quantities."

When one attempts to set forth the attitude of the teacher of economic geology the ghost of this worldly man rises and demands to be heard first. And explain as much as one may, he is never convinced, and the writer, for one, has long abandoned all hope of convincing him save by the process of making a good geologist out of his son.

This attitude of the world at large toward the science leads many of our more conservative geologists to some difference of opinion as to whether economic geology as such should be taught at all. This question, however, the writer will not undertake to discuss. It is frankly admitted at the outset that many of our best economic geologists have never received formal instruction in economic geology. If this fact be urged as an argument against such formal instruction it must be conceded that there is a certain plausibility about it. But to oppose instruction on such ground would be very like opposing formal instruction in any

[1] "Die Heterogen Gleichgewichte," II., 243.

science because some of the greatest scientific men the world has produced were self-instructed.

These questions will be settled differently by different persons, but those who have much experience of teaching realize at the beginning that in spite of individual difference some sort of an average must be discovered and followed that will come nearest to meeting the conditions, requirements, and capabilities of the majority of students. Besides, any theory that one may have regarding the best times, places, and circumstances for the study of economic geology must give way to some extent to the requirements of other studies and of other departments of the institution in which the work is done.

When Should Economic Geology be Taught. — The question as to when economic geology should be taught relates both to the age of the pupil and to the period in his education when it can be taught to the best advantage. It is the opinion of the writer based upon twenty years of experience as a teacher of geology that the results most satisfactory both to pupil and to teacher are, as a rule, to be had when the student takes up the geology at a time in life when he has sufficient maturity of mind to enable him to do logical thinking and to enjoy mental processes. There is the additional advantage in this delay that the student will have a helpful and indispensable knowledge of other branches of study. Everything is, in a sense, a prerequisite to the man who would make himself a master in the profession. There should be no hot haste about plunging into geology, and even less about plunging into some particular branch of it, any more than there is for a young man who expects to be a lawyer to go straight at the law regardless of breadth of vision and of the requirements of ordinary scholarship.

Preliminary Studies Outside of Geology. — A knowledge and facility in the use of the English language and of other modern languages that contain valuable contributions to the science of geology should be insisted upon for every one who expects to attain any distinction in economic geology. Of these the most important are German, French and Italian. These languages are essential on account of the importance of the geologic literature

they contain, while Spanish is likely to be wanted for other reasons.

One should have a sufficient familiarity with mathematics to be able to apply the methods of the engineer to the problems that will certainly need to be solved. He should have a comprehensive knowledge of inorganic chemistry; he should be well posted in physics, especially in dynamics and optics; he should have such knowledge of zoology and botany as will serve his purposes in the study of fossils. He should be well grounded in the study of economics and should have whatever our institutions of learning have to offer in the way of instruction in commercial matters.

In what is said of requirements the writer has confined himself to the barest necessities. No mention is made of those subjects which broaden a man's views and sympathies, because these things should be insisted upon for all men whether they are interested in the economic side of a subject or in some other side of it.

Evidently if one who proposes to make a profession of economic geology postpones the study of geology itself until he shall have obtained even a fair knowledge of these subjects there will be no difficulty about the ripe age and maturity of mind with which he will approach his chief study.

Preliminary Preparations in Geology. — The first thing to be taken up seriously in the study of geology should be the course in elementary geology as it is given in most of our leading universities. This course can be taken in the form of lectures, or of recitations, and should be accompanied by frequent trips in the field under the guidance of competent instructors. This course should be accompanied or followed by the study of determinative mineralogy. The student should be required not only to know how to determine any mineral, but he should have a perfect familiarity with all of the common ones and with most of the others. Elementary geology should also be followed by the study of physiography on one hand and of historical geology and paleontology on the other. While these courses are in progress and after the completion of elementary geology, the subject of economic geology should be taken up.

How Should Economic Geology be Taught? — The question as to how economic geology should be taught cannot be answered without some reference to the fact that only a limited part of a young man's life can be given to his college education and to preparation for his professional work. Nothing would be easier than to plan a course in economic geology that would keep a man in the university or technical school until he was thirty-five or forty years old, but it is not understood that such a course is contemplated. In connection with this subject of age and length of course of study some stress should be laid upon the fact that the course of study for a thoroughgoing geologist is now altogether too short. Students are in too great haste to get out in the world. Many of our best young men tell us they *must;* that they have done nothing but study all these years; and that it is their duty to begin to earn their own livelihood at least. However much we may sympathize with this point of view, we cannot lose sight of the fact that many a young man enters his profession seriously handicapped for the lack of one more year's work in the university: and they seldom make it up.

Instead of shortening the college course as has been suggested, it is our firm conviction that at least five years should be taken to complete the course of study for even a fairly equipped economic geologist. In any case it is only after the student has a comprehensive knowledge of elementary geology that he should be permitted to take up economic geology. One fatal idea by which the student himself is liable to be deluded is that one can know economic geology without knowing pure geology. No such question exists in the mind of any geologist of judgment and repute, but it is very apt to exist in the mind of a student who fancies that he has discovered a new and shorter road to the practical affairs of life and to success. Students are for the same reason often impatient of geological problems that have no evident economic bearing. The professor of geology is liable to get tired of answering questions about the utility of this, that and tother, but there seems to be no help for it, and we shall have to go on answering these same questions to the end of the chapter. But it is, and must continue to be insisted upon, that a knowledge

of the science of geology without any reference to its economic bearings is a *sine qua non* for every economic geologist. For this reason no sharp line of demarkation can be drawn between instruction in pure geology and instruction in economic geology as such.

The order in which the various topics are taken up in economic geology is probably a matter of no great importance. Every writer and lecturer on the subject has his own way of approaching it. Naturally the study of ore deposits is preceded by a study of the theories of the nature and origin of ore bodies in general. If instruction is given in the form of lectures more or less reading should be required in connection with the lectures. This reading ought not to be confined to standard works on economic geology which will usually be consulted first. Such works are necessarily out of date in regard to late developments and advances. In order to bring one's reading up to date it is necessary to consult the periodical scientific literature. Such reading answers the two-fold purpose of furnishing specific information, and of familiarizing the student with the periodic literature of geology.

The importance of a wide acquaintance with this kind of literature should be impressed upon every student. In this connection his attention should be directed to the fact that all that is written upon a given subject is not of equal value. This is a rather delicate matter to be sure, but when one finds his students quoting as seriously from a sensational Sunday supplement as from the thoughtful and well digested writings of our best geologists we cannot fail to see the necessity of their knowing how to discriminate.

Along with economic geology proper should go a broad general education, as well as a comprehensive grasp of branches cognate to geology. Of these matters one is never in danger of knowing too much for his own good or for the good of his clients. The student should not only have a working knowledge of geology, mineralogy, petrography, metallurgy, chemistry, physics and engineering, but his knowledge should embrace subjects that may at first sight appear to lie beyond the field of his legitimate operations.

He should have a pretty thorough knowledge of mining methods and of mining machinery.

He should be posted on mining laws and upon the laws relating to contracts, corporations, and business organizations.

He should understand book-keeping as related to mining operations.

He should be able to assemble, to handle, and to interpret statistical figures with facility.

Above all he should be prepared to meet certain ethical problems that are sure to arise in his profession with clean-cut ideas of right and wrong.

But it is not possible to enumerate all the branches of knowledge with which he will at one time or another need to be acquainted. The field is wide and embraces not only the things that lie legitimately within the wide field of engineering but accomplishments beyond ranging all the way from being able to make a speech in a foreign language to being able to shoot quick and straight.

In this age of specialists and specialties the economic geologist is sure to be tempted to devote himself to some one branch of the subject. He should be warned, however, against a too narrow field of operation. The man who devotes himself exclusively to the subject of magnesite would probably find too little demand for his services to enable him to earn a living. On the other hand the man who devotes himself to the geology of iron or coal may find an abundance of work if he be properly located, but none at all if he be not well located with reference to iron or coal interests.

J. C. BRANNER.

REVIEWS.

Cobalt-nickel Arsenides and Silver. By WILLET G. MILLER. 13th Rept. Ontario Bureau of Mines, 1904. Pt. I. Pp. 103. Also Cobalt-Nickel Arsenides and Silver Deposits, near Lake Temiskaming, Ontario. Fourteenth Rept. Ontario Bureau of Mines, 1905. Pt. II. Pp. 62. A map of cobalt-nickel-arsenic-silver area near Lake Temiskaming, Ontario, accompanies this report. It contains an explanatory text.

In the fall of 1903 silver-cobalt-nickel ore was discovered by a railway construction crew of the new Temiskaming and Northern Ontario Railway at a point near the boundary between the provinces of Ontario and Quebec west of the north end of Lake Temiskaming, and 330 miles north of Toronto. The nature of the ore and its value were not understood until Mr. Miller, geologist of the Ontario Bureau of Mines had visited the area late that fall. Upon recognition of the value of the discovery, there began vigorous prospecting and exploitation of the ores which has not yet reached its maximum. Figures available to date show an output for 1905 of about a million dollars, and such values are in sight as to make the district one of the important mining centers of North America.

There is apparently nothing different in the lithological conditions in the productive region from those which obtain over many thousands of square miles in Ontario. At the base of the succession are greenstones and green schists, largely of basaltic nature, mapped as Keewatin. Intrusive into the Keewatin is Laurentian granite. Unconformably upon both Keewatin and Laurentian are conglomerate and slate classed as Lower Huronian. The Lower Huronian in turn is overlaid unconformably by another sedimentary series provisionally called Middle Huronian. Finally, intrusive into and overlying these series is a great diabase or gabbro, assigned to the Keweenawan or Animikie. All

are more or less covered by glacial drift. The names used are the ones recommended for the Lake Superior region by the joint committee of Canadian and United States geologists. Mr. Miller, who was a member of this committee, is the first to publish a map showing that the rocks of northeastern Ontario can be subdivided and named much the same as the Lake Superior rocks. The Lower Huronian and Keewatin rocks, usually mapped together as Huronian by Canadian geologists, are exceedingly difficult to differentiate because of their similarity in color and texture when metamorphosed. Mr. Miller has been largely successful in this discrimination, but in a new edition of the map he would rectify boundaries and add areas, first of Keewatin, shown up largely by exploration subsequent to his mapping.

The ores are in veins, usually nearly vertical, in the Lower Huronian sediments, in the Keweenawan gabbro, and to a less extent in the Keewatin green schists. These veins vary in width from a fraction of an inch to a foot or more. While for the most part their walls are well defined and their direction constant, they frequently divide and bend. They follow with local variations systems of joints which cut the region somewhat uniformly in north to northwest and east to northeast directions. An inspection of the map of Ontario shows many of the drainage lines following approximately these directions, though it is not known that they are all controlled by joints or faults. The depth of the veins has, for the most part, not been determined, but it is known that they are most even and persistent in the Huronian sediments and the Keweenawan gabbro, and that in reaching the Keewatin below they become less uniform and persistent, a fact to which may be attributed the less common occurrence of rich veins in the Keewatin than in the overlying formations. The depth is thus practically measured by the thickness of the Lower Huronian, given as 500 feet as a maximum, but usually less.

The important ores are native silver and smaltite ($CoAs_2$). Recently at least one large vein has been shown to be *cobaltite* (CoAsS or $CoS_2.CoAs_2$). Associated with these ores in greatly varying quantities are *niccolite* (NiAs), *chloanthite* ($NiAs_2$), *millerite* (NiS), *argentite* (Ag_2S), *pyrargyrite* (Ag_3SbS_3 or

$3Ag_2S.Sb_2S_3$), *dyscrasite* (Ag_3Sb), *native bismuth, tetrahedrite* ($Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$), *chalcopyrite, bornite, mispickel* (FeAsS or $FeS_2.FeAs_2$), *iron pyrites, galena, asbolite, zinc blende,* and probably other metals and combinations. At the surface is an oxidized zone, usually but a few feet deep, perhaps because of recent glacial stripping, in which the principal minerals are *native silver, erythrite* or *cobalt bloom* and *annabergite* or what may be called *nickel bloom.* As a whole this assemblage of minerals shows remarkable similarity to those of the Joachimsthal and Annaberg districts of Germany and Austria. The average composition of the ore shipped for the quarter of the year ending June 30 was: Silver, 4.158 per cent.; cobalt, 6.890 per cent.; nickel, 3.091 per cent.; arsenic, 30.912 per cent. A characteristic feature is the predominance of arsenic over sulphur. Calcite is the chief gangue material; quartz is less important; some of the veins show very little of either. The bright pink cobalt bloom in the upper parts of the veins is conspicuous and has been the chief guide to prospectors. The leaching of other substances from the oxide zone has frequently left the native silver in large quantities, sometimes yielding a single piece weighing sixty to seventy pounds. Ores have been found which run above $3,000 per ton in value. The average for the quarter ending June 30, 1905, was $734. It is seldom that the combined values run below $200, the latter figures being approached when native silver is lacking. The ores present interesting metallurgical problems, the settlement of which must precede a standardization of values.

Mr. Miller suggests that the fissures now occupied by the cobalt-silver ores in the Lower Huronian were probably formed by the disturbance which accompanied the eruption of the diabase and gabbro, and that the ores may have been deposited from highly heated mineral-laden waters associated with the eruption. In this he is guided by the distribution of the ores with reference to the gabbro masses, by the fact that their chemical and mineralogical character is in accordance with such manner of deposition, and by association of arsenide-sulphide veins with igneous masses elsewhere. In the Sudbury district, ninety miles to the southwest, the nickel-copper sulphides and arsenides are obviously related genetically to the intrusion of the norite of that area.

The reviewer has devoted a little time to the study of the nickel-cobalt ores of this district and would emphasize Mr. Miller's view of their genetic connection with the intrusion of the gabbro. The fact of their occurrence in clear-cut fissures of the gabbro itself further raises the question whether meteoric waters may not have also played a part. Irregular, pegmatitic, quartzitic phases of the gabbro may be seen to be related to quartz veins. These quartz veins seem to be slightly earlier than the calcite veins which commonly are more uniform and carry the values of ore in the gabbro. The possibility suggests itself to the reviewer that the gradual change in deposition of quartz in small and irregular fissures to the deposition of calcite in larger and more uniform fissures may have been synchronous with the entrance of meteoric waters during or immediately following the cooling of the gabbro. It is necessary to assume only that the waters had lost their direct oxidizing influence, a condition which the heat of the gabbro may have helped to develop. There seems to be yet no satisfactory evidence of the source of the ore—whether from the gabbro itself or the intruded rocks.

Mr. Miller's last report contains an excellent summary of the occurrence of nickel-cobalt ores in North America and Europe and a general statement of the condition of the nickel-cobalt industry.

The high values of the ores, their unusual mineral combinations and their occurrence in the pre-Cambrian make this a most interesting field for economic geological studies. With the effective support of the Ontario Bureau of Mines, through Mr. Gibson, director, Mr. Miller has taken advantage of the opportunity; few pieces of geological work have been so timely and of such direct and practical assistance in the actual exploration of an ore-bearing district.

C. K. LEITH.

Asbestos. Its Occurrence, Exploitation and Uses. By F. CIRKEL. Dept. of Interior, Mines Branch. Pp. 169; Pl. XIX, 1 map, and 38 figs. Ottawa, Can., 1905.

This report is the second of a series of publications on the economic minerals of Canada, to be issued by the Mines Branch,

the first one having treated of Mica. The author treats the subject in monographic style, discussing in successive chapters: The properties and varieties of asbestos; Location and geology of Canadian deposits; Mining; Method of separation and preparation for market; Occurrence of Asbestos in foreign countries; Commercial applications.

In the first chapter the author takes up the physical and chemical properties of asbestos. The hard fibre asbestos is said to contain less chemically combined water than the soft fibre, but the latter becomes brittle if heated enough to expel a portion of its water, and this leads Mr. Cirkel to suppose that the hard fibre has been subjected to igneous heat. The statement that asbestos easily withstands temperatures of 3000° F., and that some varieties have even resisted 5000° F. will probably not be accepted by every one.

Asbestos was discovered in Canada in 1862 and mining operations began on a small scale in 1878, but the industry did not assume great importance until economical methods of handling and preparation were introduced. This however produced a revolution in the industry, and makes the Canadian deposits the principal source of the world's supply.

While a small amount of amphibole asbestos is mined in Hastings county, where it is associated with a black green hornblende rock, bounded by granite, the main supply is of course the *chrysotile,* found in two areas, the one north of Ottawa in Templeton, and the other and more important including the Thetford and Black Lake districts in the Eastern townships. In the former the serpentine occurs in crystalline limestones associated with the Grenville gneiss, while in the latter the serpentine forms disconnected masses of small extent in a great series of Cambrian slates, schists and diorites. The serpentine is regarded as the alteration product of either an olivine diabase or gabbro, and is often cut by granite dykes, which have shattered the rock, and appear to exert a strong influence on the distribution of the asbestos veins.

The author gives the views of Pratt, Merrill and Ells on the origin of the asbestos veins in the serpentine and agrees with the latter in believing that the fissures in the serpentine have been

caused by dehydration on a large scale; also that this process may have been facilitated by a loss of silica during serpentization. He thinks it probable that "the intrusion of the granitic dykes so frequently met with has facilitated the formation of numerous fissures in the immediate proximity of the intrusion, by rapid dehydration through the agency of heat." The fact that the asbestos veins increase in numbers as the granite is approached is believed to substantiate this theory. Pratt's theory of peripheral cooling is discredited, because in many cases no veins are found in the serpentine in contact with the country rock. The veins are thought to have been filled by the segregation of serpentinous matter from the sides of the fissure.

The chapters on mining, preparation and uses treat the subject in considerable detail.

The report is a valuable contribution to our literature, and it is hoped that the other economic minerals of the Dominion will be treated with equal fullness.

H. RIES.

The Clays and Clay Industry of Connecticut. By G. F. LAUGHLIN. Conn. Geol. and Nat. Hist. Surv., Bull. 4, Hartford, 1905.

This is one of the first reports issued by the recently established geological survey of Connecticut, and deals with one of its more important mineral resources. Of the seven chapters, numbers II., IV., V. and VI. deal with the origin, properties and uses of clay; the others treat specifically of the Connecticut ores. The deposits which are at present being worked are limited to the central lowland portion of the state, and to West Cornwall in Litchfield County. Those of the former area are all of pleistocene age, of low grade and sedimentary character, while those found in the latter are high grade residuals, derived from crystallines. The author gives a brief discussion of the chemical composition of the clays, and their physical character as far as determinable by simple tests, and in closing refers briefly to the brickmaking industry.

H. RIES.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

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SCIENTIFIC NOTES AND NEWS.[1]

PROFESSOR J. VOLNEY LEWIS, of Rutgers College, has been engaged, since July 1st, in an investigation of the economic geology and petrology of the Triassic trap rocks and copper deposits of New Jersey for the State Geological Survey. The chief objects in view are (1) the study of the chemical and mineralogical composition of the traps, and the origin, classification, distribution, and uses of the several varieties; (2) the determination of the character and modes of occurrence of the copper-bearing minerals, their origin and economic importance.

THE MARYLAND GEOLOGICAL SURVEY has in press a report on the Coal Deposits of Maryland which will be shortly issued under the authorship of Professor Wm. Bullock Clark, the State Geologist, and several associates. The high quality of the "Big Vein" coal of the Georges Creek basin for steam and smithing purposes and the early exploitation of the region have caused the Maryland coals to be known in the trade for more than half a century. The gradual exhaustion of the larger seam has rendered the opening up of the smaller seams a subject of much importance to the coal-mining interests of the State. To this end the State Geological Survey has for several years devoted no small part of its energies and now presents a report accompanied by numerous maps, sections, chemical analyses and calorimetric tests that is expected to be of value in the future history of coal-mining in Maryland.

AS AN OUTCOME of the formation of the division for the investigation of artesian waters by the United States Geological Survey three years ago a considerable number of geologists are now devoting their entire time to the investigation of underground

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

waters and related geology. The need of a society for the discussion of the many problems constantly arising in connection with new lines of research or investigations of more extended scope than those previously undertaken, has been felt for some time. Preliminary meetings looking to the organization of such a society were held on December 9th and 11th, and on December 20th a formal meeting was held at which the society was formally organized, a constitution adopted, and officers chosen.

The association, which is known as the "Society of Geohydrologists," is composed of active members, consisting of residents of the District of Columbia or vicinity who are principally engaged in geohydrologic work, and associate members consisting of non-residents who have contributed prominently to the science of geohydrology, making it a strictly professional society. Meetings will be held on the first and third Wednesdays of each month during the winter.

IT IS ANNOUNCED by the Director of the Geological Survey of India that a careful revision of the *Manual of economic geology of India* is being rapidly carried to completion. Before the close of the year 1906 it is hoped that this volume may be completed and much valuable knowledge on the mineral resources of India thus placed at the disposal of those who are interested in the mineral deposits of this country. It also is significant of the energy that is being displayed in the Indian Survey and in the development of the mineral wealth of the country that a mining and geological Institute of India will be shortly organized.

A RECENT CIRCULAR letter issued by the Director of the U. S. Geological Survey to the members of the scientific corps is of somewhat unusual interest to scientists and to all geologists and mining engineers who appreciate the great practical value of the scientific work which is being conducted by the Survey.

This letter, which is printed below, determines beyond peradventure the policy which has been adopted by the government bureau in regard to questions which have recently been quite widely discussed. It is felt that the public will view with much satisfaction the clearness and foresight with which these regula-

tions have been drafted. They provide effectually against the possible abuse of official privileges and ensure at the same time the wide dissemination of such results of official investigation as may have special scientific or practical importance.

Dear Sir:—Since the organization of the Geological Survey it has been the policy of the Director not only to permit but to encourage its members to publish in technical and scientific journals and in the transactions of societies technical and scientific articles, provided they do not anticipate the official publication of the results of specific investigations, of which the priority of publication rests with the Geological Survey. It has always been believed that the widest dissemination possible should be given by this means to information in the possession of the Survey, particularly where the material to be published consists of information gained or conclusions reached as a result of general reading or observation and is not the outcome of specific official investigations. Even if the writers receive compensation for such articles there does not appear to be anything objectionable in the practice, provided the writing is done outside of official hours.

When such articles are based on information that has been obtained in specific investigations, but (*a*) is contained in official reports already published or in press, or (*b*) is not considered appropriate for incorporation in an official report, permission to publish should be obtained from the Director and the fact should be stated in the article.

There does, however, appear to be some question in respect to the propriety of Survey officials being identified as editors or special contributors, or in any other intimate way, with technical or trade papers conducted as business enterprises. Such connection is apt to be used for advertising purposes and is calculated to bring criticism on the Survey organization. It is deemed best, therefore, while not abridging any of the privileges recognized in the preceding paragraphs, to prohibit such connection of Survey officials with the conduct of trade papers.

This prohibition is not intended to apply to connection with journals which are devoted entirely to the dissemination of scientific knowledge and which are not conducted for profit or as business enterprises. Such publications are SCIENCE, the NATIONAL GEOGRAPHIC MAGAZINE, the AMERICAN CHEMICAL JOURNAL, ECONOMIC GEOLOGY, FORESTRY and IRRIGATION, etc.

Very respectfully,

CHAS. D. WALCOTT,
Director.